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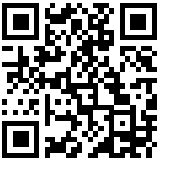

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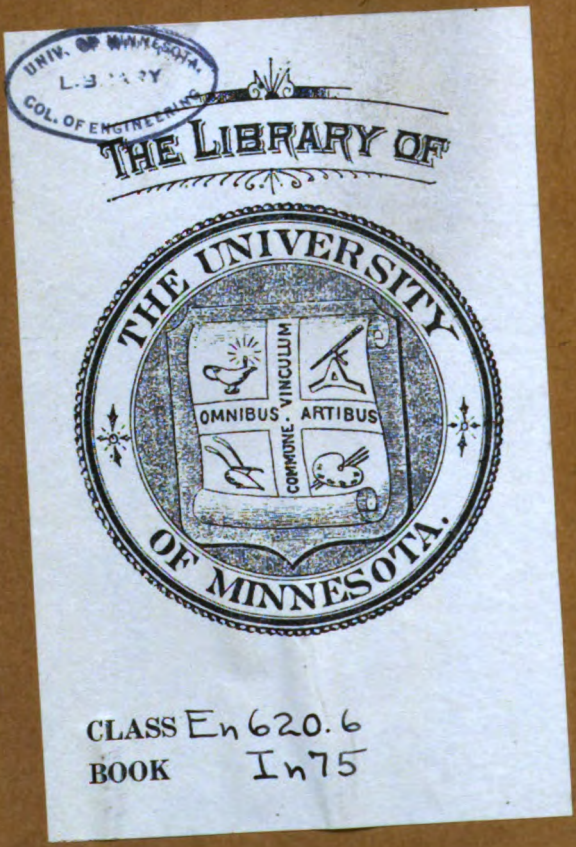

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UNIVERSITY OF

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CORRECTIONS.

Page 17, line 12, for "Mr. James B. Henderson" *read* "Mr. John B. Henderson."

Page 323, footnote, for "remark" *read* "remarks."

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OFFICERS.

1885.

PRESIDENT.

JEREMIAH HEAD, ... Middlesbrough.

PAST-PRESIDENTS.

SIR WILLIAM G. ARMSTRONG, C.B., D.C.L., LL.D., F.R.S., Newcastle-on-Tyne.
SIR LOWTHIAN BELL, BART., F.R.S., ... Northallerton.
SIR FREDERICK J. BRAMWELL, F.R.S., ... London.
THOMAS HAWKSLEY, F.R.S., ... London.
JAMES KENNEDY, ... Liverpool.
JOHN RAMSBOTTOM, ... Alderley Edge.
JOHN ROBINSON, ... Manchester.
SIR JOSEPH WHITWORTH, BART., D.C.L., LL.D., F.R.S., .. Manchester.
Sir William Fairbairn, Bart., LL.D., F.R.S., (*deceased* 1874).
Robert Napier, ... (*deceased* 1876).
John Penn, F.R.S., ... (*deceased* 1878).
Sir William Siemens, D.C.L., LL.D., F.R.S., . (*deceased* 1883).
George Stephenson, ... (*deceased* 1848).
Robert Stephenson, F.R.S., ... (*deceased* 1859).

VICE-PRESIDENTS.

DANIEL ADAMSON, ... Manchester.
E. HAMER CARBUTT, M.P., ... London.
CHARLES COCHRANE, ... Stourbridge.
DAVID GREIG, ... Leeds.
RICHARD PEACOCK, M.P., ... Manchester.
JOSEPH TOMLINSON, JUN., ... London.

MEMBERS OF COUNCIL.

PETER D. BENNETT, ... Tipton.
WILLIAM DENNY, F.R.S.E., ... Dumbarton.
BENJAMIN A. DOBSON, ... Bolton.
SIR JAMES N. DOUGLASS, ... London.
SAMUEL W. JOHNSON, ... Derby.
ALEXANDER B. W. KENNEDY, ... London.
FRANCIS C. MARSHALL, ... Newcastle-on-Tyne.
EDWARD B. MARTEN, ... Stourbridge.
ARTHUR PAGET, ... Loughborough.
R. PRICE-WILLIAMS, ... London.
SIR JAMES RAMSDEN, ... Barrow-in-Furness.
E. WINDSOR RICHARDS, ... Middlesbrough.
T. HURRY RICHES, ... Cardiff.
BENJAMIN WALKER, ... Leeds.
J. HARTLEY WICKSTEED, ... Leeds.

TREASURER.

THOMAS DRUITT.

SECRETARY.

ALFRED BACHE,

Institution of Mechanical Engineers, 10 *Victoria Chambers, London, S.W.*

[Telegraphic address:—*Mech, London.*]

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Institution of Mechanical Engineers.

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

[*Telegraph Address and Telephone No. appended within brackets.*]

1885.

HONORARY LIFE MEMBERS.

1883. Abel, Sir Frederick Augustus, C.B., D.C.L., F.R.S., Royal Arsenal, Woolwich.

1878. Crawford and Balcarres, Earl of, F.R.S., 47 Brook Street, Grosvenor Square, London, W.; Haigh Hall, Wigan; and Observatory, Dunecht, Aberdeen.

1883. Kennedy, Alexander Blackie William, Professor of Engineering, University College, Gower Street, London, W.C.

1878. Rayleigh, Lord, F.R.S., 4 Carlton Gardens, London, S.W.; and Terling Place, Witham, Essex.

1883. Trasenster, L., Rector of the University of Liége, 9 Quai de l'Industrie, Liége, Belgium.

1867. Tresca, Henri, Member of the Academy, &c., Conservatoire National des Arts et Métiers, Paris.

MEMBERS.

1878. Abbott, Thomas, Newark Boiler Works, Newark. [*Abbott, Newark.*]

1883. Abbott, William Sutherland, Locomotive Superintendent and Assistant Engineer, Alagoas Railway, Maceio, Brazil.

1861. Abel, Charles Denton, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C. [*Patentable, London.* 2729.]

1874. Abernethy, James, F.R.S.E., 4 Delahay Street, Westminster, S.W.

1876. Adams, Henry, 60 Queen Victoria Street, London, E.C.

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1879. Adams, William, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.W.

1848. Adams, William Alexander, Gaines, Worcester.

1881. Adams, William John, Messrs. Everitt Adams and Co., 35 Queen Victoria Street, London, E.C. [*Packing, London.* 1854.]

1859. Adamson, Daniel, Engineering Works, Dukinfield, near Manchester; and The Towers, Didsbury, Manchester. [*Adamson, Dukinfield.*]

1871. Adamson, Joseph, Messrs. Joseph Adamson and Co., Hyde, near Manchester. [*Adamson, Hyde.*]

1878. Adcock, Francis Louis, Post Office, Cape Town, Cape of Good Hope: (or care of William R. Adcock, 17 Rue Neuve de Berry, Havre, France.)

1851. Addison, John, Colehill Cottage, Fulham, London, S.W.

1858. Albaret, Auguste, Engine Works, Liancourt-Rantigny, Oise, France.

1885. Alderson, George Beeton, Messrs. Allen Alderson and Co., Alexandria, Egypt; Sheen Mount, East Sheen, London, S.W.: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1883. Allam, Edwin Clerk, Normanhurst, Romford.

1847. Allan, Alexander, Glen House, The Valley, Scarborough.

1875. Allan, George, New British Iron Works, Corngreaves, near Birmingham; and Corngreaves Hall, near Birmingham.

1884. Allen, Alfred Evans, 37 Wellington Street, Hull.

1881. Allen, Percy Ruskin, Anglo-American Brush Electric Light Co., Victoria Works, Vine Street, York Road, Lambeth, London, S.E.; and Woodberrie Hill, Loughton, Essex.

1884. Allen, Samuel Wesley, 65 Bute Street, Bute Docks, Cardiff.

1865. Allen, William Daniel, Bessemer Steel Works, Sheffield.

1885. Allen, William Henry, Messrs. W. H. Allen and Co., York Street Works, Lambeth, London, S.E. [*Pump, London.*]

1882. Allen, William Milward, Principal Assistant Engineer, Engine Boiler and Employers' Liability Insurance Co., 12 King Street, Manchester.

1870. Alley, John, care of W. Cuningham, Moscow.

1877. Alley, Stephen, Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow.

1865. Alleyne, Sir John Gay Newton, Bart., Chevin, Belper.

1884. Alleyne, Reynold Henry Newton, Messrs. Scriven and Co., Leeds Old Foundry, Marsh Lane, Leeds.

1872. Alliott, James Bingham, Messrs. Manlove Alliott Fryer and Co., Bloomsgrove Works, Ilkeston Road, Nottingham.

1876. Allport, Charles James, care of Howard A. Allport, Dodworth Grove, Barnsley.

1871. Allport, Howard Aston, Dodworth Grove, Barnsley.

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1884. Almond, Harry John, 81 Cannon Street Buildings, 139 Cannon Street, London, E.C.

1867. Amos, James Chapman, West Barnet Lodge, Lyonsdown, Barnet.

1876. Anderson, Henry John Card, Temple Sheen, East Sheen, London, S.W.

1856. Anderson, Sir John, LL.D., F.R.S.E., Fairleigh, The Mount, St. Leonard's-on-Sea.

1881. Anderson, Joseph Liddell, Messrs. Anderson and Gallwey, Hydraulic Machine Works, Lot's Road, Chelsea, London, S.W.

1884. Anderson, Samuel, General Manager, Westbury Iron Works, Westbury, Wiltshire.

1856. Anderson, William, Messrs. Easton and Anderson, Erith Iron Works, Erith, S. O., Kent; and 3 Whitehall Place, London, S.W. [3695.]

1885. Anson, Frederick Henry, 15 Dean's Yard, Westminster, S.W.

1858. Appleby, Charles Edward, Charing Cross Chambers, Duke Street, Adelphi, London, W.C.

1867. Appleby, Charles James, Messrs. Appleby Brothers, 89 Cannon Street, London, E.C. [*Millwright, London.* 1731.]; and East Greenwich Works, London, S.E.

1874. Aramburu y Silva, Fernando, Messrs. Aramburu and Sons, Cartridge Manufacturers, Calle de la Virgen de las Azucenas, Madrid: (or care of Manuel Cardenosa, 86 Great Tower Street, London, E.C.)

1881. Archbold, Joseph Gibson, Messrs. Fawcett Preston and Co., Phœnix Foundry, 17 York Street, Liverpool; and 176 Upper Parliament Street, Liverpool.

1874. Archer, David, Central Chambers, Corporation Street, Birmingham; and 275 Pershore Road, Birmingham.

1883. Arens, Henrique, Messrs. Arens and Irmaos, Engineering Works, Rio de Janeiro, Brazil: (or care of Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.)

1882. Armer, James, Messrs. J. and E. Hall, Iron Works, Dartford. [*Armer, Hallford, Dartford;* or *Armer, Sidcup.*]

1859. Armitage, William James, Farnley Iron Works, Leeds.

1879. Armstrong, Alexander, Melrose, North Shore, Auckland, New Zealand.

1866. Armstrong, George, Great Western Railway, Locomotive Department, Stafford Road Works, Wolverhampton.

1882. Armstrong, George Frederick, Professor of Engineering, The University, Edinburgh.

1876. Armstrong, William, Jun., Mining Engineer, Wingate Colliery, County Durham.

1858. Armstrong, Sir William George, C.B., D.C.L., LL.D., F.R.S., Elswick, Newcastle-on-Tyne; and Cragside, Morpeth.

1870. Armstrong, William Irving, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

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1873. Arnold, David Nelson, Messrs. Willans Arnold and Co., Spanish Steel Works, Sheffield.

1879. Arrol, Thomas Arthur, Messrs. Arrol Brothers, Germiston Iron Works, Glasgow; and 18 Blythswood Square, Glasgow.

1873. Ashbury, Thomas (*Life Member*), 28A Market Street, Manchester. [*Thomas Ashbury, Manchester.*]

1884. Ashwell, Frank, 10 Erskine Street, Leicester.

1881. Aspinall, John Audley Frederick, Locomotive Superintendent, Great Southern and Western Railway, Dublin.

1877. Astbury, James, Smethwick Foundry, near Birmingham.

1870. Atkinson, Charles Fanshawe, Messrs. Marriott and Atkinson, Fitzalan Steel Works, Sheffield. [*Marriott's, Sheffield.* 174.]

1875. Atkinson, Edward (*Life Member*), care of Messrs. Mackenzie and Brougham, 15 Great George Street, Westminster, S.W.

1882. Aveling, Thomas Lake, Messrs. Aveling and Porter, Rochester.

1879. Bagot, Alan Charles, care of Edward W. Bowles, 86 Cambridge Street, London, S.W.

1872. Bagshaw, Walter, Messrs. J. Bagshaw and Sons, Victoria Foundry, Batley. [*Bagshaw, Batley.*]

1865. Bailey, John, Villa des Arts, Boulogne-sur-mer, France.

1885. Bailey, William Henry, Albion Works, Salford, Manchester.

1880. Baillie, Robert, Messrs. Westwood Baillie and Co., London Yard Iron Works, Poplar, London, E.

1872. Bailly, Philimond, 62 Rue de la Victoire, Paris.

1880. Bain, William Neish, Messrs. Kyle and Bain, Hong Kong Ice Works, Eastpoint, Hong Kong, China; and Collingwood, 7 Aytoun Road, Pollockshields, Glasgow.

1873. Baird, George, St. Petersburg; and 13 Berkeley Square, London, W.

1875. Bakewell, Herbert James, Engineer, Department of the Controller of the Navy, Admiralty, Whitehall, London, S.W.

1877. Bale, Manfred Powis, Appold Street, Finsbury, London, E.C.

1884. Balmokand, Lala, Assistant Engineer, Public Works Department, Punjaub, India; care of Lala Shamba Das, Said Mitha, Lahore, India.

1879. Banderali, David, Assistant Locomotive and Carriage Superintendent, Chemin de fer du Nord, Paris.

1870. Barber, Thomas, Mining Engineer, High Park Collieries, Eastwood, Nottinghamshire.

1870. Barclay, Arthur, Westfield, Surbiton, R.O., Kingston-on-Thames.

1885. Barker, Tom Birkett, Scholefield Street, Birmingham.

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1884. Barlow, Elias, Messrs. William Muir and Co., Britannia Works, Sherborne Street, Strangeways, Manchester.

1882. Barlow, Henry Bernoulli, Cornbrook Heald Works, Chester Road, Manchester. [*Monopoly, Manchester.*]

1875. Barlow, William Henry, F.R.S., 2 Old Palace Yard, Westminster, S.W.

1880. Barlow-Massicks, Thomas, Millom Iron Works, Millom, Cumberland.

1881. Barnett, John Davis, Mechanical Superintendent, Midland Railway, Port Hope, Ontario, Canada.

1884. Barr, Archibald, Professor of Engineering, Yorkshire College, Leeds.

1878. Barr, James, Calside Villa, Paisley.

1883. Barras, Harry Haywood, Locomotive Superintendent, Southern Brazilian Rio Grande do Sul Railway, Rio Grande do Sul, Brazil; (or care of George Thomas Barras, 7 Howard Street, Rotherham.)

1879. Barratt, Samuel, Engineer and Manager, Corporation Gas Works, Rochdale Road Station, Manchester.

1882. Barrett, John James, Sewlal Motilal Cotton Mill, Tardeo, Bombay.

1885. Barrie, William, Outside Superintendent Engineer, Nippon Yusen Kaisha Steam Ship Co., Yokohama, Japan.

1862. Barrow, Joseph, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]

1867. Barrows, Thomas Welch, Messrs. Barrows and Stewart, Portable Engine Works, Banbury. [*Barrows, Banbury.*]

1871. Barry, John Wolfe, 23 Delahay Street, Westminster, S.W. [*Wolfebarry, London.* 3024.]

1883. Bartlett, James Herbert, Standard Building, Montreal, Canada.

1883. Bastin, Edwin Philp, Alliance Engineering Works, West Drayton, near Uxbridge.

1860. Batho, William Fothergill, 9 Victoria Chambers, Victoria Street, Westminster, S.W. [*Othniel, London.* 3138.]

1881. Bawden, William, Assistant Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1872. Bayliss, Thomas Richard, Adderley Park Rolling Mills and Metal Works, Birmingham; and Belmont, Northfield, Birmingham.

1877. Beale, William Phipson, 12 Old Square, London, W.C.; and 19 Upper Phillimore Gardens, Kensington, London, W.

1881. Beattie, Alfred Luther, Manager, New Zealand Railway Workshops, Dunedin, Otago, New Zealand.

1882. Beattie, Frank, Queen Chambers, 88 Colmore Row, Birmingham.

1880. Beaumont, William Worby, 163 Strand, London, W.C.

1859. Beck, Edward (*Life Member*), Dallam Forge, Warrington; and 21 Bold Street, Warrington.

1873. Beck, William Henry, 115 Cannon Street, London, E.C.

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1875. Beckwith, John Henry, Manager, Messrs. W. and J. Galloway and Sons, Knott Mill Iron Works, Manchester.

1882. Bedson, Joseph Phillips, Messrs. Richard Johnson and Nephew, Bradford Iron Works, Manchester.

1875. Beeley, Thomas, Engineer and Boiler Maker, Hyde Junction Iron Works, Hyde, near Manchester.

1884. Beetlestone, George John, 94 St. Mary Street, Cardiff.

1885. Bell, Charles Lowthian, Clarence Iron Works, Middlesbrough.

1858. Bell, Sir Lowthian, Bart., F.R.S., Clarence Iron Works, Middlesbrough; Rounton Grange, Northallerton; Reform Club, Pall Mall, London, S.W.; and care of the Hon. E. Lyulph Stanley, 82 Harley Street, London, W. [*Sir Lowthian Bell, Middlesbrough.*]

1880. Bell, William Henry, Bolivia: care of Sir W. G. Armstrong Mitchell and Co., 8 Great George Street, Westminster, S.W.

1879. Bellamy, Charles James, 38 Parliament Street, Westminster, S.W.

1868. Belliss, George Edward, Steam Engine and Boiler Works, Ledsam Street, Birmingham.

1878. Belsham, Maurice, Messrs. Price and Belsham, 52 Queen Victoria Street, London, E.C.

1880. Benham, Percy, Messrs. Benham, 66 Wigmore Street, London, W. [*Benham, London.* 7065.]

1854. Bennett, Peter Duckworth, Horseley Iron Works, Tipton.

1878. Berrier-Fontaine, Marc, Ingénieur de la Marine, Toulon Dockyard, Toulon, France: (or care of Messrs. P. S. King and Son, Canada Buildings, King Street, Westminster, S.W.) [*Berrier, Toulon.*]

1861. Bessemer, Sir Henry, F.R.S., Denmark Hill, London, S.E.

1866. Bevis, Restel Ratsey, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead; and Manor Hill, Birkenhead.

1874. Bewick, Thomas John, Mining Engineer, Suffolk House, Laurence Pountney Hill, London, E.C.

1870. Bewlay, Hubert, Birmingham Heath Boiler Works, Spring Hill, Birmingham.

1882. Bewley, Thomas Arthur, Messrs. Bewley Webb and Co., Port of Dublin Ship Yard, Dublin.

1885. Bicknell, Arthur Channing, Sandycroft Foundry, Chester.

1883. Bicknell, Edward, Locomotive Superintendent, La Guaira and Caracas Railway, Venezuela; and 8 Canynge Square, Clifton, Bristol.

1884. Bika, Léon Joseph, Locomotive Engineer-in-Chief, Belgian State Railway, 29 Rue des Palais, Bruxelles.

1877. Birch, Robert William Peregrine, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1847. Birley, Henry, 6 Brentwood, Pendleton, R.O., Manchester.

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1875. Bisset, William Harvey, Board of Trade Office, Falmouth; and Erin Lodge, Green Bank, Falmouth.
1879. Black, William, Messrs. Black Hawthorn and Co., Gateshead.
1862. Blake, Henry Wollaston, F.R.S., Messrs. James Watt and Co., 90 Leadenhall Street, London, E.C.
1881. Blechynden, Alfred, Rio Tinto Mines, Huelva, Spain.
1867. Bleckly, John James, Bewsey Iron Works, Warrington; and Daresbury Lodge, Altrincham.
1882. Blundstone, Samuel Richardson, 2 Victoria Mansions, Victoria Street, Westminster, S.W.
1881. Bocquet, William, Locomotive Engineer, Scinde Punjaub and Delhi Railway, Lahore, India.
1883. Bodden, George, Messrs. William Bodden and Son, Hargreaves Spindle and Flyer Works, Oldham.
1863. Boeddinghaus, Julius, Electrotechniker, Düsseldorf, Germany.
1884. Bone, William Lockhart, Works of the Ant and Bee, West Gorton, Manchester.
1880. Borodin, Alexander, Engineer-in-Chief, Russian South Western Railways, Kieff, Russia.
1885. Boughton, Henry Francis, Dan Rylands, Glass Works, Barnsley.
1878. Bourdon, François Edouard, 74 Faubourg du Temple, Paris: (or care of Messrs. Negretti and Zambra, Holborn Viaduct, London, E.C.)
1884. Bourne, James Johnstone, Abberley, Wallington, Surrey.
1879. Bourne, William Temple, Messrs. Bourne and Grove, Bridge Steam Saw Mills, Worcester.
1879. Bovey, Henry Taylor, Professor of Engineering, McGill University, Montreal, Canada.
1880. Bow, William, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]
1870. Bower, Anthony, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.
1858. Bower, John Wilkes (*Life Member*), Neston, near Chester.
1882. Bowie, Augustus Jesse, Jun., Mining and Hydraulic Engineer, P.O. Drawer 2220, San Francisco, California, United States.
1869. Boyd, William, Wallsend Slipway and Engineering Works, Wallsend, near Newcastle-on-Tyne. [*Wall, Newcastle-on-Tyne; Wall, Cardiff.*]
1884. Boyer, Robert Skeffington, Pier Head Chambers, Cardiff.
1882. Bradley, Frederic, Clensmore Foundry, Kidderminster.
1878. Bradley, Frederick Augustus, 39 Queen Victoria Street, London, E.C.
1881. Bradley, Thomas, Wellington Foundry, Newark.
1878. Braithwaite, Charles C., 35 King William Street, London Bridge, London, E.C.

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1875. Braithwaite, Richard Charles, Norfolk House, Handsworth, R. O., Birmingham. [*Braithwaite, Westbromwich.*]

1854. Bramwell, Sir Frederick Joseph, F.R.S., 5 Great George Street, Westminster, S.W. [*Wellbram, London.* 3060.]

1885. Brearley, Benjamin J., Ravenhead Plate Glass Works, Ravenhead, St. Helen's.

1868. Breeden, Joseph, New Mill Works, Fazeley Street, Birmingham.

1883. Bricknell, Augustus Lea, Merlin Engineering Works, Brixton Rise, London, S.W.

1881. Briggs, John Henry, Howden.

1880. Bright, Thomas Smith, 1 Northampton Villas, St. Helen's Road, Swansea.

1865. Brock, Walter, Messrs. Denny and Co., Engine Works, Dumbarton.

1879. Brodie, John Shanks, Town Surveyor and Harbour Engineer, Town Hall, Whitehaven.

1852. Brogden, Henry (*Life Member*), Hale Lodge, Altrincham, near Manchester.

1884. Brook-Fox, Frederick George, Executive Engineer, Bellary Kistna State Railway, Cumbum, Madras Presidency, India.

1880. Brophy, Michael Mary, Messrs. James Slater and Co., 251 High Holborn, London, W.C.

1874. Brotherhood, Peter, 15 and 17 Belvedere Road, Lambeth, London, S.E.; and 94 Cromwell Road, South Kensington, London, S.W.

1866. Brown, Andrew Betts, Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.

1885. Brown, Benjamin, Widnes Foundry, Widnes.

1879. Brown, Charles, Manager, Maschinenfabrik, Oerlikon, Switzerland: (or care of Dr. Gardiner Brown, 9 St. Thomas' Street, London Bridge, London, S.E.)

1880. Brown, Francis Robert Fountaine, Mechanical Superintendent, Canadian Pacific Railway, Montreal, Canada.

1881. Brown, George William, Reading Iron Works, Reading.

1863. Brown, Henry, Waterloo Chambers, Waterloo Street, Birmingham.

1884. Brown, Oswald, 27 Great George Street, Westminster, S.W. [*Acqua, London.* 3054.]

1874. Browne, Tomyns Reginald, Assistant District Locomotive Superintendent, East Indian Railway, Allahabad, India: (or care of Messrs. B. Smyth and Co., 1 New China Bazaar Street, Calcutta.)

1874. Bruce, George Barclay, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1867. Bruce, William Duff, Vice-Chairman, Port Commission, Calcutta.

1873. Brunel, Henry Marc, 23 Delahay Street, Westminster, S.W. [3024.]

1870. Brunlees, James, F.R.S.E., 5 Victoria Street, Westminster, S.W.

1884. Bryan, William B., Engineer, East London Water Works, Old Ford, London, E.

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1873. Buckley, Robert Burton, Executive Engineer, Indian Public Works Department, Writers' Buildings, Calcutta: (or care of H. Burton Buckley, 1 St. Mary's Terrace, Paddington, London, W.)

1877. Buckley, Samuel, Messrs. Buckley and Taylor, Castle Iron Works, Oldham.

1878. Buddicom, Harry William, Moreton Villa, Abergavenny.

1874. Buddicom, William Barber, Penbedw Hall, Mold, Flintshire.

1872. Budenberg, Arnold, Messrs. Schaeffer and Budenberg, 1 Southgate, St. Mary's Street, Manchester. [*Manometer, Manchester.* 899.]

1882. Budge, Enrique, Engineer-in-Chief, Harbour Works, Valparaiso, Chile.

1881. Bulkley, Henry Wheeler, 149 Broadway, New York.

1884. Bullock, Joseph Henry, General Manager, Pelsall Coal and Iron Works, near Walsall.

1882. Bulmer, John, Spring Garden Engineering Works, Pitt Street, Newcastle-on-Tyne.

1884. Bunning, Charles Ziethen, Mining Engineer of the Government Coal Mines, Warora, Central Provinces, India.

1884. Bunt, Thomas, Superintendent Engineer, Kiangnan Arsenal, Shanghai, China: (or care of R. Pearce, Lanarth House, Holders Hill, Hendon, London, N.W.)

1884. Bunting, George Albert, Rio Tinto Mines, Huelva, Spain.

1885. Burder, Walter Chapman, Messrs. Messenger and Co., Loughborough.

1877. Burgess, James Fletcher, 14 Almeric Road, Clapham Junction, London, S.W.

1881. Burn, Robert Scott, Oak Lea, Edgeley Road, near Stockport.

1874. Burn, William Edward, Ashleigh Villa, Willow Brae Road, Edinburgh.

1878. Burnett, Robert Harvey, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1878. Burrell, Charles, Jun., Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford.

1885. Burrell, Frederick John, Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford.

1877. Burton, Clerke, 22 Oakfield Street, Roath, Cardiff.

1870. Bury, William, 5 New London Street, London, E.C.

1884. Butcher, Joseph John, 4 St. Nicholas' Buildings, Newcastle-on-Tyne.

1882. Butler, Edmund, Kirkstall Forge, near Leeds.

1877. Campbell, Angus, Superintendent of the Government Foundry and Workshops, Roorkee, India.

1880. Campbell, Daniel, Messrs. Campbell and Schultz, 90 Cannon Street, London, E.C. [*Duke, London.* 1893.]

1869. Campbell, James, Hunslet Engine Works, Leeds.

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1882. Campbell, John, Messrs. R. W. Deacon and Co., Kalimaas Works, Soerabaya, Java.

1885. Capito, Charles Alfred Adolph, Messrs. Capito and Hardt, Metropolitan Buildings, 63 Queen Victoria Street, London, E.C.; and 7 Nygade, Copenhagen. [*Capito Hardt, London.*]

1860. Carbutt, Edward Hamer, M.P., 19 Hyde Park Gardens, London, W.

1878. Cardew, Cornelius Edward, Locomotive and Carriage Superintendent, State Railways Establishment, Public Works Department, Government of India: care of Messrs. King King and Co., Bombay: (or care of Rev. J. H. Cardew, Keynshambury House, Cheltenham.)

1875. Cardozo, Francisco Corrêa de Mesquita (*Life Member*), Messrs. Cardozo and Irmão, Pernambuco Engine Works, Pernambuco, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

1878. Carlton, Thomas William, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C. [1618.]; and 1 Canfield Gardens, Priory Road, West Hampstead, London, N.W.

1869. Carpmael, Frederick, 57 Arlingford Road, Tulse Hill Gardens, Brixton, London, S.W.

1866. Carpmael, William, 24 Southampton Buildings, London, W.C. [*Carpmael, London.* 2608.]

1877. Carr, Robert, Resident Engineer, London and St. Katharine Docks Co., London Docks, Upper East Smithfield, London, E.

1884. Carrick, Henry, Messrs. Carrick and Wardale, Redheugh Engine Works, Gateshead; and Holly House, Gateshead.

1874. Carrington, William T. H., 9 and 11 Fenchurch Avenue, London, E.C.

1877. Carter, Claude, Manager, Messrs. Hetherington and Co., Ancoats Works, Pollard Street, Manchester.

1885. Carter, Herbert Fuller, Rio Tinto Mines, Huelva, Spain.

1877. Carter, William, Ingénieur-en-Chef, Société anonyme du Phœnix, Ghent, Belgium.

1870. Carver, James, Lace Machine Works, Alfred Street, Nottingham.

1883. Cawley, George, Assistant Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1876. Challen, Stephen William, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham.

1884. Chamberlain, John, Assistant Engineer, Gas Light and Coke Co.'s Tar and Liquor Works, Beckton, London, E.

1882. Chapman, Hedley, Messrs. Chapman Carverhill and Co., Scotswood Road, Newcastle-on-Tyne.

1866. Chapman, Henry, 113 Victoria Street, Westminster, S.W.; and 10 Rue Laffitte, Paris.

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1878. Chapman, James Gregson, Messrs. Fawcett Preston and Co., Phœnix Foundry, Liverpool; and 25 Austinfriars, London, E.C. [*Fawcett, London.*]
1885. Chapman, John, Engineer, Windsor and Eton Water Works, Eton.
1885. Charnock, George Frederick, Engineering Department, Technical College, Bradford.
1877. Chater, John, Messrs. Henry Pooley and Son, 89 Fleet Street, London, E.C.
1872. Chatwin, Thomas, Victoria Works, Great Tindal Street, Ladywood, Birmingham.
1873. Cheesman, William Talbot, Hartlepool Rope Works, Hartlepool.
1881. Chilcott, William Winsland, Devonport Dockyard, Devonport.
1883. Childe, Rowland, Mining Engineer, Stamp Office Place, Wakefield.
1877. Chisholm, John, Messrs. William Muir and Co., Sherborne Street, Manchester; and 30 Devonshire Street, Higher Broughton, Manchester.
1857. Chrimes, Richard, Messrs. Guest and Chrimes, Brass Works, Rotherham.
1880. Churchward, George Dundas, Box 717, General Post Office, Sydney, New South Wales; or care of A. W. Churchward, London Chatham and Dover Railway, Queenborough Pier, Queenborough; and Kersney Manor, Dover.
1871. Clark, Christopher Fisher, Mining Engineer, Garswood Coal and Iron Co., Park Lane Collieries, Wigan; and Cranbury Lodge, Park Lane, Wigan. [*Park Lane, Wigan.*]
1878. Clark, Daniel Kinnear, 8 Buckingham Street, Adelphi, London, W.C.
1859. Clark, George, Sen., Southwick Engine Works, near Sunderland (*deceased*).
1867. Clark, George, Southwick Engine Works, near Sunderland.
1869. Clark, William, Mining Engineer, Teversall Collieries, near Mansfield.
1865. Clarke, John, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds. [*Loco, Leeds.* 504.]
1869. Clarke, William, Messrs. Clarke Chapman and Gurney, Victoria Works, South Shore, Gateshead.
1870. Clayton, Nathaniel, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.
1882. Clayton, William Wikeley, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds.
1871. Cleminson, James, 7 Westminster Chambers, Victoria Street, Westminster, S.W. [*Cleminson, London.* 3046.]
1873. Clench, Frederick, Messrs. Robey and Co., Globe Iron Works, Lincoln. [*Robey, Lincoln.*]
1885. Close, John, Jun., York Engineering Works, Leeman Road, York.
1885. Clutterbuck, Herbert, 3 Westbourne Grove, Coatham, R.O., Redcar.
1882. Coates, Joseph, Messrs. Robey and Co., Globe Iron Works, Lincoln.
1883. Coath, David Decimus, Agricultural Implement Works and Saw Mill, Rangoon, British Burmah, India.

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1881. Cochrane, Brodie, Mining Engineer, Aldin Grange, Durham.
1858. Cochrane, Charles, Woodside Iron Works, near Dudley; and The Grange, Stourbridge.
1885. Cochrane, John, Grahamston Foundry and Engine Works, Barrhead, near Glasgow.
1869. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.
1868. Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne; and Oakfield House, Gosforth, Newcastle-on-Tyne.
1867. Cockey, Francis Christopher, Selwood Iron Works, Frome.
1864. Coddington, William, M.P., Ordnance Cotton Mill, Blackburn; and Wycolla, Blackburn.
1876. Coe, William John, 1 Rumford Place, Liverpool.
1847. Coke, Richard George, Mining Engineer, 39 Holywell Street, Chesterfield; and Brimington Hall, near Chesterfield.
1884. Cole, Charles, Messrs. Cole Marchent and Co., Prospect Foundry, Bowling, near Bradford.
1878. Cole, John William, Elm Cottage, Osmond Terrace, Norwood, Adelaide, South Australia: (or care of Messrs. James Sinton and Co., 7 St. Benet Place, Gracechurch Street, London, E.C.)
1878. Coles, Henry James, Sumner Street, Southwark, London, S.E.
1877. Coley, Henry, Mansion House Chambers, Queen Victoria Street, London, E.C.
1884. Collenette, Ralph, Hæmatite Iron and Steel Works, Barrow-in-Furness.
1884. Colquhoun, James, General Manager, Tredegar Iron Coal and Steel Works, Tredegar.
1884. Coltman, John Charles, Messrs. Huram Coltman and Son, Engineering Works, Meadow Lane, Loughborough.
1878. Colyer, Frederick, 18 Great George Street, Westminster, S.W.
1881. Compton-Bracebridge, John Edward, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.
1874. Conyers, William, Engineer, Bluff Harbor Board, Campbelltown, Otago, New Zealand.
1877. Cooper, Arthur, North Eastern Steel Co., Royal Exchange, Middlesbrough.
1883. Cooper, Charles Friend, Messrs. Paterson and Cooper, Telegraph Works, Pownall Road, Dalston, London, E. [*Patella, London.* 1140.]
1877. Cooper, George, Engineer and General Manager, Buenos Aires Great Southern Railway, Buenos Aires: (or care of Secretary, Buenos Aires Great Southern Railway, 4 Great Winchester Street, London, E.C.)
1874. Cooper, William, Neptune Foundry, Hull.
1881. Coote, Arthur, Messrs. R. and W. Hawthorn Leslie and Co., Hebburn, Newcastle-on-Tyne.

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1881. Copeland, Charles John, Messrs. Westray Copeland and Co., Barrow-in-Furness.

1885. Coppée, Evence, 223 Avenue Louise, Brussels.

1884. Corder, George Alexander, Chief Engineer, Chinese Naval Service, Amoy, China; care of Commissioner of Customs, Amoy, China.

1878. Cornes, Cornelius, 6 Norfolk Crescent, Bath, [*Stothert, Cornes, Bath.*]; and 30 Walbrook, London, E.C. [*Stothert, Cornes, London.*]

1848. Corry, Edward, 9 New Broad Street, London, E.C.

1881. Cosser, Thomas, McLeod Road Iron Works, Kurrachee, India.

1875. Cotton, Francis Michael, Metropolitan Board of Works, Spring Gardens, London, S.W.

1884. Cotton, John, Messrs. E. Ripley and Sons, Bowling Dye Works, Bradford.

1875. Cottrill, Robert Nivin, Beehive Works, Bolton.

1868. Coulson, William, Mining Engineer, 32 Crossgate, Durham; and Shamrock House, Durham.

1878. Courtney, Frank Stuart, 3 Whitehall Place, London, S.W.

1882. Courtney, William McDougall, 15 Elizabeth Terrace, Upper William Street North, Sydney, New South Wales.

1875. Coward, Edward, Messrs. Melland and Coward, Cotton Mills and Bleach Works, Heaton Mersey, near Manchester.

1875. Cowen, Edward Samuel, Messrs. G. R. Cowen and Co., Beck Foundry, Brook Street, Nottingham; and 9 Rope Walk Street, Nottingham.

1870. Cowen, George Roberts, Messrs. G. R. Cowen and Co., Beck Foundry, Brook Street, Nottingham; and 9 Rope Walk Street, Nottingham.

1880. Cowper, Charles Edward, 6 Great George Street, Westminster, S.W.

1847. Cowper, Edward Alfred, 6 Great George Street, Westminster, S.W.

1878. Coxhead, Frederick Carley, 27 Leadenhall Street, London, E.C.

1883. Crampton, George, 4 Victoria Street, Westminster, S.W.

1847. Crampton, Thomas Russell, 4 Victoria Street, Westminster, S.W.

1882. Craven, John, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.

1871. Craven, Joseph, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.

1866. Craven, William, Vauxhall Iron Works, Osborne Street, Manchester.

1884. Crighton, John, Messrs. J. and R. Crighton, Helena Street, Ancoats, Manchester.

1873. Crippin, Edward Frederic, Mining Engineer, Brynn Hall Colliery, Ashton, near Wigan.

1883. Croft, Henry, Chemanns, Vancouver Island.

1878. Crohn, Frederick William, 16 Burney Street, Greenwich, S.E.

1877. Crompton, Rookes Evelyn Bell, Arc Works, Chelmsford; and Mansion House Buildings, Queen Victoria Street, London, E.C.

1884. Crook, Charles Alexander, Telegraph Construction and Maintenance Works, Enderby's Wharf, East Greenwich, London, S.E.

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1883. Cropper, Henry S., Minerva Works, Alfred Street North, Nottingham.

1881. Crosland, James Foyell Lovelock, Chief Assistant Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1865. Cross, James, Messrs. John Hutchinson and Co., Alkali Works, Widnes; and Ditton Lodge, Warrington.

1882. Cross, William, Messrs. R. and W. Hawthorn Leslie and Co., St Peter's Works, Newcastle-on-Tyne.

1871. Crossley, William, 153 Queen Street, Glasgow. [*Crossley, Glasgow.* 584.]

1875. Crossley, William John, Messrs. Crossley Brothers, Great Marlborough Street, Manchester.

1882. Cruickshank, William Douglass, Chief Government Engineer Surveyor, Marine Board, Sydney, New South Wales.

1884. Cureton, Barnard John, Manager, Patent Nut and Bolt Works, Smethwick, near Birmingham.

1875. Curtis, Richard, Messrs. Curtis Sons and Co., Phœnix Works, Chapel Street, Manchester.

1876. Cutler, Samuel, Providence Iron Works, Millwall, London, E. [*Cutler, Millwall.* 5059.]

1879. Dady, Jamsetjee Nesserwanjee, 10 Dady Sett House, Fort, Bombay, India.

1864. Daglish, George Heaton, St. Helen's Foundry, St. Helen's, Lancashire. [*Daglish, St. Helen's.*]

1883. D'Albert, Charles, Messrs. Hotchkiss and Co., 6 Route de Gonesse, St. Denis, near Paris; and 16 Rue des Chesneaux, Montmorency, Seine-et-Oise, France.

1881. D'Alton, Patrick Walter, London Mutual Boiler Insurance Co., 17 Queen Victoria Street, London, E.C.

1866. Daniel, Edward Freer, Messrs. Worthington and Co., The Brewery, Burton-on-Trent; and 89 Derby Street, Burton-on-Trent.

1866. Daniel, William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds; and Oxford House, Horsforth, Leeds.

1878. Darwin, Horace (*Life Member*), The Orchard, Huntingdon Road, Cambridge.

1873. Davey, Henry, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds.

1883. Davidson, George, Superintendent Engineer, Australasian Steam Navigation Co., Sydney, New South Wales.

1865. Davidson, James, Laboratory Department, Royal Arsenal, Woolwich.

1881. Davidson, James, Engineering Works, Cumberland Street, Dunedin, Otago, New Zealand: (or care of Messrs. Buxton Ronald and Co., 24 Basinghall Street, London, E.C.)

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1884. Davidson, James Young, Manager, Nagpur and Chhattisgarh, and Wardha Coal State Railways, Nagpur, Central Provinces, India; (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)

1884. Davies, Alfred Herbert, Eskell Chambers, Market Place, Nottingham.

1881. Davies, Benjamin, Bleach Works, Adlington, near Chorley.

1880. Davies, Charles Merson, Locomotive Superintendent, Nagpur and Chhattisgarh State Railway, Nagpur, Central Provinces, India.

1885. Davies, Edward John Mines, 82 Kingsdown Parade, Bristol.

1874. Davis, Alfred, Parliament Mansions, Westminster, S.W.

1868. Davis, Henry Wheeler, 38 New Broad Street, London, E.C.

1873. Davis, John Henry, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester; and 147 Cannon Street, London, E.C.

1877. Davison, John Walter, 1 Meshansky, Banny pereoulok, Moscow, Russia: (or care of Alfred L. Sacré, 60 Queen Victoria Street, London, E.C.)

1884. Davison, Robert, Caledonian Railway, Locomotive Department, St. Rollox, Glasgow.

1873. Davy, David, Messrs. Davy Brothers, Park Iron Works, Sheffield.

1874. Davy, Walter Scott, Hæmatite Iron and Steel Works, Barrow-in-Furness.

1883. Daw, James Gilbert, Messrs. Nevill Druce and Co., Llanelly Copper Works, Llanelly.

1874. Daw, Samuel, Ivy Tor, 15 Westhouse Road, Penarth.

1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.

1879. Dawson, Bernard, 110 Cannon Street, London, E.C. [*Crocus, London.*]; and The Laurels, Malvern Link, Malvern. [*Heather, Malvern Link.*]

1869. Day, St. John Vincent, 115 St. Vincent Street, Glasgow.

1874. Deacon, George Frederick, Municipal Offices, Dale Street, Liverpool.

1880. Deacon, Richard William, Boeboetan, Clive Road, Penarth.

1883. Dean, Francis Winthrop, East Taunton, Massachusetts, United States.

1868. Dean, William, Locomotive Superintendent, Great Western Railway, Swindon. [*Loco, Swindon.*]

1866. Death, Ephraim, Messrs. Death and Ellwood, Albert Works, Leicester.

1884. Decauville, Paul, Portable Railway Works, Petit Bourg, Seine et Oise, France.

1877. Dees, James Gibson, 36 King Street, Whitehaven.

1858. Dempsey, William, 26 Great George Street, Westminster, S.W.

1882. Denison, Samuel, Jun., Messrs. Samuel Denison and Son, Old Grammar School Foundry, North Street, Leeds. [*Weigh, Leeds.* 221.]

1883. Dennis, William Frederick, 101 Leadenhall Street, London, E.C. [*Fredennis, London.* 559.]

1882. Denny, William, F.R.S.E., Messrs. William Denny and Sons, Leven Ship Yard, Dumbarton. [*Denny, Dumbarton.*]

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1880. De Pape, William Alfred Harry, Tottenham Board of Health, Coombes Croft House, High Road, Tottenham, Middlesex.

1883. Dick, Frank Wesley, Steel Company of Scotland, Blochairn Steel Works, Glasgow.

1882. Dick, Gavin Gemmell, 1 Westminster Chambers, Victoria Street, Westminster, S.W.

1880. Dickinson, John, Palmer's Hill Engine Works, Sunderland. [*Bede, Sunderland.*]

1875. Dickinson, William, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.

1879. Dickson, John, Willowbank, Darlington.

1883. Dixon, Samuel, Messrs. Kendall and Gent, Victoria Works, Springfield, Salford, Manchester.

1872. Dobson, Benjamin Alfred, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton. [*Dobsons, Bolton.*]

1873. Dobson, Richard Joseph Caistor, Suiker Fabriek, Kalibayor, Banjoemas, Java: (or care of Charles E. S. Dobson, 4 Chesterfield Buildings, Victoria Park, Clifton, Bristol.)

1880. Dodd, John, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1868. Dodman, Alfred, Highgate Foundry, Lynn. [*Dodman, Lynn.*]

1880. Donald, James, Messrs. Donald Henesey and Couper, Ripon Iron Works, Frere Road, Bombay: (or care of Messrs. Fleming Wilson and Co., 24, 25, 27 Rood Lane, Fenchurch Street, London, E.C.)

1876. Donaldson, John, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.; and Tower House, Turnham Green.

1873. Donkin, Bryan, Jun., Messrs. B. Donkin and Co., Blue Anchor Road, Bermondsey, London, S.E.

1884. Donnelly, John, Assistant Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.W.; and 70 Studley Road, Clapham Road, London, S.W.

1865. Douglas, Charles Prattman, Consett Iron Works, near Blackhill, County Durham; and Parliament Street, Consett, County Durham.

1879. Douglass, Sir James Nicholas, Trinity House, London, E.C. [2242.]

1879. Douglass, William, Chief Engineer to the Commissioners of Irish Lights, Westmoreland Street, Dublin.

1879. Doulton, Bernard, Lambeth Pottery, Lambeth, London, S.E.

1857. Dove, George, Messrs. Cowans Sheldon and Co., St. Nicholas Engine and Iron Works, Carlisle; and Viewfield, Stanwix, near Carlisle.

1873. Dove, George, Jun., Redbourn Hill Iron and Coal Co., Frodingham, near Doncaster. [*Redbourn, Frodingham.*]

1866. Downey, Alfred C., Messrs. Downey and Co., Coatham Iron Works, Middlesbrough; and Post Office Chambers, Middlesbrough.

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1881. Dowson, Joseph Emerson, 3 Great Queen Street, Westminster, S.W.
1880. Doxford, Robert Pile, Messrs. William Doxford and Sons, Pallion Shipbuilding and Engine Works, Sunderland.
1874. Dredge, James, 35 Bedford Street, Strand, London, W.C.
1877. Dübs, Charles Ralph, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.
1877. Dübs, Henry John Sillars, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.
1885. Duckering, Charles, Water Side Works, Rosemary Lane, Lincoln.
1880. Duckham, Frederic Eliot, Engineer, Millwall Docks, London, E.
1881. Duckham, Heber, 184 Lewisham Road, London, S.E. [*Duckham, London.*]
1879. Duncan, David John Russell, Messrs. Duncan Brothers, 32 Queen Victoria Street, London, E.C. [*Doucine, London.*]; and 10 Airlie Gardens, Kensington, London, W.
1870. Dunlop, James Wilkie, 49 Albert Street, Regent's Park, London, N.W.
1881. Dunn, Henry Woodham, Knysna, Cape Colony.
1885. Durham, Frederick William, 23 Leadenhall Street, London, E.C. [*Oilring, London.*]
1865. Dyson, Robert, Messrs. Owen and Dyson, Rother Iron Works, Rotherham.

1880. Eager, John Edward, Messrs. William Crichton and Co., Engineering and Shipbuilding Works, Abo, Finland.
1869. Earnshaw, William Lawrence, Superintending Marine Engineer, South Eastern Railway, Folkestone.
1858. Easton, Edward, 11 Delahay Street, Westminster, S.W.
1884. Eastwood, Charles, Manager, Linacre Gas Works, Liverpool.
1875. Eaves, William, Engineer, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.
1878. Eckart, William Roberts, Messrs. Salkeld and Eckart, 632 Market Street, P. O. Box 1587, San Francisco, California, United States.
1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.
1883. Edmiston, James Brown, Marine Superintending Engineer, Messrs. Hamilton Fraser and Co., K Exchange Buildings, Liverpool; and Ivy Cottage, Highfield Road, Walton, Liverpool.
1871. Edwards, Edgar James, Messrs. Morewood and Co., Woolford Iron Works, Soho, Birmingham.
1877. Edwards, Frederick, 62 Bishopsgate Street Within, London, E.C.
1880. Edwards, Robert, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.
1866. Elce, John, 9 Hopwood Avenue, Manchester.

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1879. Ellacott, Robert Henry, Messrs. Ellacott and Co., Plymouth Foundry, Plymouth. [*Ellacott, Plymouth.* 47.]

1875. Ellington, Edward Bayzand, Hydraulic Engineering Works, Chester; and Hydraulic Engineering Co., Palace Chambers, 9 Bridge Street, Westminster, S.W.

1859. Elliot, Sir George, Bart., M.P., Houghton-le-Spring, near Fence Houses.

1883. Elliott, Henry John, Assistant Manager, Elliott's Metal Works, Selly Oak, near Birmingham.

1869. Elliott, Henry Worton, Metal Sheathing Works, 10 Coleshill Street, Birmingham; and Selly Oak Works, near Birmingham.

1882. Elliott, Thomas Graham, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1880. Ellis, Oswald William, 26 George Street, Edinburgh.

1885. Elsworthy, Edward Houtson, Messrs. Richardson and Cruddas, Byculla Iron Works, Bombay, India.

1869. Elwell, Alfred, Edge Tool Works, Wood Green, Wednesbury.

1875. Elwell, Thomas, Messrs. Varrall Elwell and Middleton, 1 Avenue Trudaine, Paris.

1878. Elwin, Charles, Metropolitan Board of Works, Spring Gardens, London, S.W.

1884. Etherington, John, 39A King William Street, London Bridge, London, E.C.

1884. Evans, David, Barrow Hæmatite Steel Works, Barrow-in-Furness.

1885. Evans, Richard Kendall, Engineering Works, Sandiacre, near Nottingham.

1864. Everitt, William Edward, Messrs. Allen Everitt and Sons, Kingston Metal Works, Adderley Street, Birmingham; and Finstal, Bromsgrove.

1881. Ewen, Thomas Buttwell, Messrs. Tangye Brothers, Cornwall Works, Soho, near Birmingham.

1869. Faija, Henry, 4 Great Queen Street, Westminster, S.W.

1868. Fairbairn, Sir Andrew, M.P., Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds; and 15 Portman Square, London, W.

1875. Farcot, Jean Joseph Léon, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1880. Farcot, Paul, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1867. Fardon, Thomas, 106 Queen Victoria Street, London, E.C.; and 63 Collingdon Street, Luton.

1881. Farrar, Sidney Howard, Messrs. Howard Farrar and Co., Port Elizabeth, South Africa; and 69 Cornhill, London, E.C.

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1882. Fawcett, Thomas Constantine, Burmantofts Foundry, Leeds.
1884. Fearfield, John Piggin, Lace Machine Works, Stapleford, near Nottingham.
1882. Feeny, Victor Isidore, 106 Queen Victoria Street, London, E.C.
1876. Fell, John Corry, 1 Queen Victoria Street, London, E.C.; and Excelsior Works, Old Street, London, E.C.
1877. Fenton, James, 8 Great George Street, Westminster, S.W.
1869. Fenwick, Clennell, Victoria Docks Engine Works, Victoria Docks, London, E.
1870. Ferguson, Henry Tanner, Locomotive Superintendent, Punjaub Northern State Railway, Rawal Pindi, Punjaub, India.
1881. Ferguson, William, Harbour Board, Wellington, New Zealand: (or care of Montgomery Ferguson, 81 James Street, Dublin.)
1854. Fernie, John, P.O. Box 57, Philadelphia, Pennsylvania, United States.
1866. Fiddes, Walter, Engineer, Bristol United Gas Works, Bristol.
1872. Fidler, Edward, Prescot Colliery, Prescot.
1867. Field, Edward, Chandos Chambers, 22 Buckingham Street, Adelphi, London, W.C.
1884. Fielden, Joseph Petrie, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.
1874. Fielding, John, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester.
1884. Fisher, Henry Oakden, Engineer, Taff Vale Railway, Cardiff.
1885. Fitton, Joseph, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
1877. Flannery, James Fortescue, 9 Fenchurch Street, London, E.C. [2283.]
1864. Fleet, Thomas, Crown Boiler and Gasholder Works, Swan Village, Westbromwich.
1847. Fletcher, Edward, 2 Osborne Avenue, West Jesmond, Newcastle-on-Tyne.
1885. Fletcher, Edward, Messrs. William Collier and Co., Worsley Street, New Bailey Street, Salford, Manchester.
1883. Fletcher, George, Masson Works, Derby.
1872. Fletcher, Herbert, Ladyshore Colliery, Little Lever, Bolton; and The Hollins, Bolton.
1867. Fletcher, Lavington Evans, Chief Engineer, Manchester Steam Users' Association, 9 Mount Street, Albert Square, Manchester.
1872. Flower, James J. A., Messrs. James Flower and Sons, St. Mary's Chambers, St. Mary Axe, London, E.C. [*Floramour, London.* 551.]
1859. Fogg, Robert, 11 Queen Anne's Gate, Westminster, S.W.
1877. Forbes, Daniel Walker, Smithfield Works, New Road, Blackwall, London, E.
1882. Forbes, David Moncur, Engineer, H. M. Mint, Calcutta.
1882. Forbes, William George Loudon Stuart, Superintendent of General Workshops, H. M. Mint, Calcutta.

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1861. Forster, Edward, Messrs. Chance Brothers and Co., Glass Works, Spon Lane, near Birmingham.

1882. Forsyth, Robert Alexander, 28 Tunnel Terrace, Newport, Monmouthshire.

1884. Foster, John Slater, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1882. Fothergill, John Reed, Superintendent Marine Engineer, 1 Bathgate Terrace, West Hartlepool.

1877. Foulis, William, Engineer, Glasgow Corporation Gas Works, 42 Virginia Street, Glasgow.

1885. Fourny, Hector Foster, Messrs. Earle's Shipbuilding and Engineering Works, Hull.

1866. Fowler, George, Basford Hall, near Nottingham.

1847. Fowler, Sir John, K.C.M.G., 2 Queen Square Place, Westminster, S.W.

1885. Fowler, William Henry, Manchester Steam Users' Association, 9 Mount Street, Albert Square, Manchester.

1866. Fox, Charles Douglas, 2 Victoria Mansions, Victoria Street, Westminster, S.W.

1875. Fox, Samson, Leeds Forge, Leeds.

1882. Fox, William, Leeds Forge, Leeds.

1884. Frampton, Edwin, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E. [*Oxygen, London.* 8007.]

1885. Franki, James Peter, Morts Dock and Engineering Co., Morts Bay, Sydney, New South Wales: (or care of Messrs. Mort and Co., 155 Fenchurch Street, London, E.C.)

1877. Fraser, John Hazell, Messrs. Fraser Brothers, Railway Iron Works, Bromley, London, E. [*Pressure, London.* 5420.]

1876. Frost, William, Manager, Carlisle Steel and Engine Works, Sheffield; and Woodhill, Sheffield.

1866. Fry, Albert, Bristol Wagon Works, Lawrence Hill, Bristol.

1884. Furness, Edward, Metropolitan Buildings, 63 Queen Victoria Street, London, E.C.

1882. Furrell, Edward Wyburd, Exmouth.

1866. Galloway, Charles John, Messrs. W. and J. Galloway and Sons, Knott Mill Iron Works, Manchester. [*Galloway, Manchester.*]

1862. Galton, Capt. Douglas, C.B., R.E., F.R.S., 12 Chester Street, Grosvenor Place, London, S.W.

1880. Galwey, John Wilfrid de Villemont, Messrs. Galwey Whitehead and Co., Warrington Engine and Iron Works, Lythgoe's Lane, Warrington.

1884. Ganga Ram, Lala, Executive Engineer, Public Works Department, Amritsar, Punjaub, India.

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1882. Garrett, Frank, Messrs. Richard Garrett and Sons, Leiston Works, Leiston, R.S.O., Suffolk. [*Garrett, Leiston.*]

1867. Gauntlett, William Henry, 33 Albert Terrace, Middlesbrough. [*Pyrometer, Middlesbrough.*]

1880. Geoghegan, Samuel, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin.

1871. Gibbins, Richard Cadbury, Berkley Street, Birmingham.

1872. Gilbert, Ebenezer Edwin, Canada Engine Works, Montreal, Canada.

1883. Gilchrist, Percy Carlyle, Palace Chambers, 9 Bridge Street, Westminster, S.W. [*Gilchrist, London.*]

1856. Gilkes, Edgar, Messrs. Thompson and Gilkes, Stockton-on-Tees; and Ingleside, Stockton-on-Tees.

1880. Gill, Charles, Messrs. Young and Gill, Engineering Works, Java; and Java Lodge, Beckenham.

1866. Gilroy, George, Engineer, Ince Hall Colliery, Wigan.

1884. Gimson, Arthur James, Messrs. Gimson and Co., Engine Works, Vulcan Street, Leicester. [*Gimson, Leicester.* 6.]

1884. Girdlestone, John Ward, Engineer, Bristol Docks, Bristol.

1881. Girdwood, William Wallace, Indestructible Packing Works, 9 Lea Place, East India Dock Road, Poplar, London, E.

1874. Gjers, John, Messrs. Gjers Mills and Co., Ayresome Iron Works, Middlesbrough.

1862. Godfrey, Samuel, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough; and Beaconsfield House, North Ormesby, Middlesbrough.

1880. Godfrey, William Bernard, 54 Regent's Park Road, Regent's Park, London, N.W.

1882. Goldsmith, Alfred Joseph, Messrs. John Walker and Co., Union Foundry and Shipbuilding Works, Maryborough, Queensland.

1879. Goldsworthy, Robert Bruce, Messrs. Thomas Goldsworthy and Sons, Britannia Emery Mills, Hulme, Manchester.

1867. Gooch, William Frederick, Vulcan Foundry, Newton-le-Willows, Lancashire.

1884. Good, Henry, Messrs. Jardine and Co., Shanghai, China: care of Marine Engineers' Institute, Shanghai, China.

1877. Goodbody, Robert, Messrs. Goodbody, Clashawaun Jute Factory, Clara, near Moate, Ireland.

1869. Goodeve, Thomas Minchin, 5 Crown Office Row, Temple, London, E.C.

1875. Goodfellow, George Ben, Hyde Iron Works, Hyde, near Manchester.

1884. Goodger, Walter William, Messrs. Handyside and Co., Derby.

1885. Goodwin, Arnold, Jun., 56 Sumner Street, Southwark, London, S.E.

1865. Göransson, Göran Fredrick, Sandvik Iron Works, near Gefle, Sweden: (or care of F. W. Lonergan, 121 Cannon Street, London, E.C.)

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1875. Gordon, Robert, Executive Engineer, Public Works Department, Henzada, British Burmah, India: (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)

1879. Gorman, William Augustus, Messrs. Siebe and Gorman, 187 Westminster Bridge Road, London, S.E. [*Siebe, London.*]

1880. Gottschalk, Alexandre, 13 Rue Auber, Paris.

1877. Goulty, Wallis Rivers, Messrs. Wheatley Kirk, Price, and Goulty, Albert Chambers, Albert Square, Manchester. [*Indicator, Manchester.*]

1878. Grafton, Alexander, 113 Cannon Street, London, E.C.

1865. Gray, John McFarlane, Chief Examiner of Engineers, Marine Department, Board of Trade; 86 Osborn Road, Forest Gate, London, E.

1876. Gray, John William, Engineer, Corporation Water Works, Broad Street, Birmingham.

1879. Gray, Thomas Lowe, Rokesley House, St. Michael's Road, Stockwell, London, S.W.

1879. Greathead, James Henry, 8 Victoria Chambers, Victoria Street, Westminster, S.W.

1861. Green, Edward, M.P., Messrs. E. Green and Son, Phœnix Works, Wakefield.

1871. Greener, John Henry, 14 St. Swithin's Lane, London, E.C.

1878. Greenwood, Arthur, Messrs. Greenwood and Batley, Albion Works, Leeds.

1874. Greenwood, William Henry, Professor of Metallurgy and Mechanical Engineering, Firth College, Sheffield.

1865. Greig, David, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds. [*Greig, Fowler, Leeds.* 155.]

1885. Greig, David, Jun., Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1880. Gresham, James, Messrs. Gresham and Craven, Craven Iron Works, Ordsal Lane, Salford, Manchester.

1883. Grew, Frederick, 12 Stockleigh Road, St. Leonard's-on-Sea.

1874. Grew, Nathaniel, Dashwood House, 9 New Broad Street, London, E.C.

1866. Grice, Sir Edwin James, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1868. Grierson, Henry Houldsworth, Moss Brow, Warburton, near Warrington.

1884. Griffiths, James E., Mount Stuart Square, Cardiff.

1873. Griffiths, John Alfred, Priory Mill, Coventry; and 2 Chester Street, Coventry.

1879. Grose, Arthur, Manager, Vulcan Iron Works, Guildhall Road, Northampton.

1870. Guilford, Francis Leaver, Messrs. G. R. Cowen and Co., Beck Foundry, Brook Street, Nottingham.

1883. Guinotte, Lucien, Mariemont and Bascoup Collieries, Mariemont, Belgium.

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1884. Gulland, James Ker, Diamond Drill Co., 6A Victoria Street, Westminster, S.W. [*Gulland, London.*]

1870. Gwynne, James Eglinton Anderson (*Life Member*), Essex Street Works, Strand, London, W.C. [*Gwynnegram, London.*]

1870. Gwynne, John, Hammersmith Iron Works, Hammersmith, London, W.

1879. Hadfield, Robert, Hadfield Steel Foundry Co., Attercliffe, Sheffield.

1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.

1884. Hall, Albert Francis, George F. Blake Manufacturing Co., 44 Washington Street, Boston; and 3 Cordis Street, Charlestown, Boston, Massachusetts, United States.

1879. Hall, John Francis, Messrs. W. Jessop and Sons, Brightside Steel Works, Sheffield.

1881. Hall, John Percy, Engine Works Department, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow.

1882. Hall, John Willim, Foundry and Engine Works, Blaydon-on-Tyne, R.S.O., County Durham.

1874. Hall, Thomas Bernard, Patent Nut and Bolt Works, Smethwick, near Birmingham; and Ingleside, Sandon Road, Edgbaston, Birmingham.

1871. Hall, William Silver, Messrs. Hall and Clarke, Canal Street Iron Works, Derby [*Canal, Derby.*]; and 39 Hartington Street, Derby. [*Silverhall, Derby.*]

1880. Hallett, John Harry, 120 Powell's Place, Bute Docks, Cardiff.

1871. Halpin, Druitt, 9 Victoria Chambers, Victoria Street, Westminster, S.W. [*Halpin, London.*]

1870. Hamand, Arthur Samuel, 9 Bridge Street, Westminster, S.W.

1875. Hammond, Walter John, Resident Engineer and Locomotive Superintendent, Paulista Railway, Jundiahy, São Paulo, Brazil; (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

1870. Hannah, Joseph Edward, Liverpool Corporation Water Works, Llanforda Offices, Oswestry.

1874. Harding, William Bishop, Muzeum-utcza 9-ik szam, Budapest, Hungary.

1881. Hardingham, George Gatton Melhuish, 191 Fleet Street, London, E.C. [*Hardingham, London.*]

1883. Hardy, John George, Vacuum Brake Co., 7 Hohenstaufengasse, Vienna.

1869. Harfield, William Horatio, Mansion House Buildings, Queen Victoria Street, London, E.C.

1884. Harker, Harold Hayes, Locomotive Superintendent, Minas and Rio Railway, Cruzeiro, Rio de Janeiro, Brazil.

1873. Harman, Harry Jones, 22 Booth Street, Manchester.

1879. Harris, Henry Graham, 5 Great George Street, Westminster, S.W.

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1885. Harris, John Henry, Worthington Pumping Engine Co., 114 Queen Victoria Street, London, E.C. [*Tuncharp, London.*]

1873. Harris, Richard Henry, 63 Queen Victoria Street, London, E.C.

1877. Harris, William Wallington, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.; and 24 Alexandra Villas, Hornsey Park, London, N.

1885. Harrison, Frederick Henry, Lincoln Malleable Iron Works, Lincoln.

1885. Harrison, Joseph, Normal School of Science, South Kensington, London, S.W.

1858. Harrison, Thomas Elliot, Engineer-in-Chief, North Eastern Railway, Newcastle-on-Tyne.

1883. Hart, Frederick, Pottstown, Montgomery County, Pennsylvania, United States: (or care of A. Pye-Smith, Messrs. Samuel Osborn and Co., 16 Philpot Lane, London, E.C.)

1877. Hart, James, 138 Portland Street, Southport.

1882. Hart, Norman, care of Colonel Beaumont, 2 Victoria Mansions, Victoria Street, Westminster, S.W.

1872. Hartnell, Wilson, Benson's Buildings, Park Row, Leeds.

1882. Harvey, Charles Randolph, Messrs. G. and A. Harvey, Albion Machine Works, Govan, near Glasgow.

1883. Harvey, Robert, Messrs. North and Harvey, Liverpool Nitrate Works, Iquique, Chile.

1878. Harwood, Robert, Soho Iron Works, Bolton.

1882. Haskins, John Ferguson, 114A Queen Victoria Street, London, E.C.

1881. Haslam, Alfred Seale, Union Foundry, Derby. [*Zero, Derby.*]

1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.

1885. Hatton, Robert James, Henley's Telegraph Works, North Woolwich, London, E.

1857. Haughton, S. Wilfred (*Life Member*), Greenbank, Carlow, Ireland.

1878. Haughton, Thomas, 110 Cannon Street, London, E.C. [*Haughnot, London.*]

1885. Haughton, Thomas James, Mining Engineer, 69 Brecknock Road, London, N.

1861. Hawkins, William Bailey, 39 Lombard Street, London, E.C.

1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.

1856. Hawksley, Thomas, F.R.S., 30 Great George Street, Westminster, S.W.

1873. Hay, James A. C., Superintendent of Machinery to the War Department, Royal Arsenal, Woolwich.

1882. Hayes, Edward, Watling Works, Stony Stratford. [*Hayes, Stony Stratford.*]

1879. Hayes, John, 27 Leadenhall Street, London, E.C. [*Orbit, London.*]

1862. Haynes, Thomas John, Calpe Foundry and Forge, North Front, Gibraltar.

1880. Hayter, Harrison, 33 Great George Street, Westminster, S.W.

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1869. Head, Jeremiah, Messrs. Fox Head and Co., Newport Rolling Mills, Middlesbrough. [*Head, Foxhead, Middlesbrough.* 22.]

1873. Headly, Lawrance, Exchange Iron Foundry and Implement Works, Corn Exchange Street, Cambridge; and 1 Camden Place, Cambridge. [*Vanes, Cambridge.*]

1857. Healey, Edward Charles, 163 Strand, London, W.C.

1872. Heap, William, 9 Rumford Place, Liverpool. [*Metal, Liverpool.* 809.]

1864. Heathfield, Richard, Messrs. Morewood and Co., Lion Galvanising Works, Birmingham Heath, Birmingham.

1875. Heenan, Richard Hammersley, Messrs. Heenan and Froude, Newton Heath Iron Works, near Manchester. [*Spherical, Newton Heath.*]

1879. Henchman, Humphrey, care of John Henchman, Uplands, Wallington, Surrey.

1869. Henderson, David Marr, Engineer-in-Chief, Imperial Maritime Customs Service of China, Shanghai, China.

1883. Henderson, John Baillie, Engineer to the Queensland Government, Water Supply Department, Brisbane, Queensland.

1883. Henderson, William, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.

1878. Henesey, Richard, Messrs. Donald Henesey and Couper, Ripon Iron Works, Frere Road, Bombay; and 3 Beckett Terrace, Uxbridge.

1879. Henriques, Cecil Quixam, Parliament Mansions, Westminster, S.W.

1875. Hepburn, George, Redeross Chambers, Redeross Street, Liverpool. [*Hepburn, Liverpool.*]

1876. Heppell, Thomas, Mining Engineer, Ouston Collieries, Chester-le-Street.

1877. Hepworth, Thomas Howard, Curzon House, Curzon Street, Derby.

1884. Hernu, Arthur Henry, 35 Bedford Street, Strand, London, W.C.

1884. Hervey, Matthew Wilson, Assistant Engineer, West Middlesex Water Works, Hammersmith, London, W.

1879. Hesketh, Everard, Messrs. J. and E. Hall, Iron Works, Dartford. [*Hesketh, Dartford.*]

1865. Hetherington, John Muir, Vulcan Works, Pollard Street, Manchester.

1866. Hetherington, Thomas Ridley, Vulcan Works, Pollard Street, Manchester.

1872. Hewlett, Alfred, Haseley Manor, Warwick.

1872. Hewlett, William Henry, Wigan Coal and Iron Works, Kirkless Hall, Wigan.

1871. Hick, John, M.P., Mytton Hall, Whalley, near Blackburn.

1885. Hicken, Thomas, Dunchurch, Rugby.

1864. Hide, Thomas C., 4 Cullum Street, Fenchurch Street, London, E.C.

1879. Higson, Jacob, Mining Engineer, Crown Buildings, 18 Booth Street Manchester.

1871. Hill, Alfred C., Clay Lane Iron Works, South Bank, R.S.O., Yorkshire.

1885. Hill, Robert Anderson, Royal Mint, Little Tower Hill, London, E.

1882. Hiller, Henry, Chief Engineer, National Boiler Insurance Company, 22 St. Ann's Square, Manchester.

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PROCEEDINGS.

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CORRECTIONS.

Page 17, line 12, for "Mr. James B. Henderson" *read* "Mr. John B. Henderson."

Page 323, footnote, for "remark" *read* "remarks."

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OFFICERS.

1885.

PRESIDENT.

JEREMIAH HEAD, ... Middlesbrough.

PAST-PRESIDENTS.

SIR WILLIAM G. ARMSTRONG, C.B., D.C.L., LL.D., F.R.S., Newcastle-on-Tyne.
SIR LOWTHIAN BELL, BART., F.R.S., ... Northallerton.
SIR FREDERICK J. BRAMWELL, F.R.S., ... London.
THOMAS HAWKSLEY, F.R.S., ... London.
JAMES KENNEDY, ... Liverpool.
JOHN RAMSBOTTOM, ... Alderley Edge.
JOHN ROBINSON, ... Manchester.
SIR JOSEPH WHITWORTH, BART., D.C.L., LL.D., F.R.S., .. Manchester.
Sir William Fairbairn, Bart., LL.D., F.R.S., (*deceased* 1874).
Robert Napier, ... (*deceased* 1876).
John Penn, F.R.S., ... (*deceased* 1878).
Sir William Siemens, D.C.L., LL.D., F.R.S., . (*deceased* 1883).
George Stephenson, ... (*deceased* 1848).
Robert Stephenson, F.R.S., ... (*deceased* 1859).

VICE-PRESIDENTS.

DANIEL ADAMSON, ... Manchester.
E. HAMER CARBUTT, M.P., ... London.
CHARLES COCHRANE, ... Stourbridge.
DAVID GREIG, ... Leeds.
RICHARD PEACOCK, M.P., ... Manchester.
JOSEPH TOMLINSON, JUN., ... London.

MEMBERS OF COUNCIL.

PETER D. BENNETT, ... Tipton.
WILLIAM DENNY, F.R.S.E., ... Dumbarton.
BENJAMIN A. DOBSON, ... Bolton.
SIR JAMES N. DOUGLASS, ... London.
SAMUEL W. JOHNSON, ... Derby.
ALEXANDER B. W. KENNEDY, ... London.
FRANCIS C. MARSHALL, ... Newcastle-on-Tyne.
EDWARD B. MARTEN, ... Stourbridge.
ARTHUR PAGET, ... Loughborough.
R. PRICE-WILLIAMS, ... London.
SIR JAMES RAMSDEN, ... Barrow-in-Furness.
E. WINDSOR RICHARDS, ... Middlesbrough.
T. HURRY RICHES, ... Cardiff.
BENJAMIN WALKER, ... Leeds.
J. HARTLEY WICKSTEED, ... Leeds.

TREASURER.

THOMAS DRUITT.

SECRETARY.

ALFRED BACHE,

Institution of Mechanical Engineers, 10 Victoria Chambers, London, S.W.

[Telegraphic address:—*Mech, London.*]

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Institution of Mechanical Engineers.

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

[*Telegraph Address and Telephone No. appended within brackets.*]

1885.

HONORARY LIFE MEMBERS.

1883. Abel, Sir Frederick Augustus, C.B., D.C.L., F.R.S., Royal Arsenal, Woolwich.

1878. Crawford and Balcarres, Earl of, F.R.S., 47 Brook Street, Grosvenor Square, London, W.; Haigh Hall, Wigan; and Observatory, Dunecht, Aberdeen.

1883. Kennedy, Alexander Blackie William, Professor of Engineering, University College, Gower Street, London, W.C.

1878. Rayleigh, Lord, F.R.S., 4 Carlton Gardens, London, S.W.; and Terling Place, Witham, Essex.

1883. Trasenster, L., Rector of the University of Liége, 9 Quai de l'Industrie, Liége, Belgium.

1867. Tresca, Henri, Member of the Academy, &c., Conservatoire National des Arts et Métiers, Paris.

MEMBERS.

1878. Abbott, Thomas, Newark Boiler Works, Newark. [*Abbott, Newark.*]

1883. Abbott, William Sutherland, Locomotive Superintendent and Assistant Engineer, Alagoas Railway, Maceio, Brazil.

1861. Abel, Charles Denton, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C. [*Patentable, London.* 2729.]

1874. Abernethy, James, F.R.S.E., 4 Delahay Street, Westminster, S.W.

1876. Adams, Henry, 60 Queen Victoria Street, London, E.C.

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1879. Adams, William, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.W.

1848. Adams, William Alexander, Gaines, Worcester.

1881. Adams, William John, Messrs. Everitt Adams and Co., 35 Queen Victoria Street, London, E.C. [*Packing, London.* 1854.]

1859. Adamson, Daniel, Engineering Works, Dukinfield, near Manchester; and The Towers, Didsbury, Manchester. [*Adamson, Dukinfield.*]

1871. Adamson, Joseph, Messrs. Joseph Adamson and Co., Hyde, near Manchester. [*Adamson, Hyde.*]

1878. Adcock, Francis Louis, Post Office, Cape Town, Cape of Good Hope: (or care of William R. Adcock, 17 Rue Neuve de Berry, Havre, France.)

1851. Addison, John, Colehill Cottage, Fulham, London, S.W.

1858. Albaret, Auguste, Engine Works, Liancourt-Rantigny, Oise, France.

1885. Alderson, George Beeton, Messrs. Allen Alderson and Co., Alexandria, Egypt; Sheen Mount, East Sheen, London, S.W.: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1883. Allam, Edwin Clerk, Normanhurst, Romford.

1847. Allan, Alexander, Glen House, The Valley, Scarborough.

1875. Allan, George, New British Iron Works, Corngreaves, near Birmingham; and Corngreaves Hall, near Birmingham.

1884. Allen, Alfred Evans, 37 Wellington Street, Hull.

1881. Allen, Percy Ruskin, Anglo-American Brush Electric Light Co., Victoria Works, Vine Street, York Road, Lambeth, London, S.E.; and Woodberrie Hill, Loughton, Essex.

1884. Allen, Samuel Wesley, 65 Bute Street, Bute Docks, Cardiff.

1865. Allen, William Daniel, Bessemer Steel Works, Sheffield.

1885. Allen, William Henry, Messrs. W. H. Allen and Co., York Street Works, Lambeth, London, S.E. [*Pump, London.*]

1882. Allen, William Milward, Principal Assistant Engineer, Engine Boiler and Employers' Liability Insurance Co., 12 King Street, Manchester.

1870. Alley, John, care of W. Cuningham, Moscow.

1877. Alley, Stephen, Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow.

1865. Alleyne, Sir John Gay Newton, Bart., Chevin, Belper.

1884. Alleyne, Reynold Henry Newton, Messrs. Scriven and Co., Leeds Old Foundry, Marsh Lane, Leeds.

1872. Alliott, James Bingham, Messrs. Manlove Alliott Fryer and Co., Bloomsgrove Works, Ilkeston Road, Nottingham.

1876. Allport, Charles James, care of Howard A. Allport, Dodworth Grove, Barnsley.

1871. Allport, Howard Aston, Dodworth Grove, Barnsley.

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1884. Almond, Harry John, 81 Cannon Street Buildings, 139 Cannon Street, London, E.C.

1867. Amos, James Chapman, West Barnet Lodge, Lyonsdown, Barnet.

1876. Anderson, Henry John Card, Temple Sheen, East Sheen, London, S.W.

1856. Anderson, Sir John, LL.D., F.R.S.E., Fairleigh, The Mount, St. Leonard's-on-Sea.

1881. Anderson, Joseph Liddell, Messrs. Anderson and Gallwey, Hydraulic Machine Works, Lot's Road, Chelsea, London, S.W.

1884. Anderson, Samuel, General Manager, Westbury Iron Works, Westbury, Wiltshire.

1856. Anderson, William, Messrs. Easton and Anderson, Erith Iron Works, Erith, S. O., Kent; and 3 Whitehall Place, London, S.W. [3695.]

1885. Anson, Frederick Henry, 15 Dean's Yard, Westminster, S.W.

1858. Appleby, Charles Edward, Charing Cross Chambers, Duke Street, Adelphi, London, W.C.

1867. Appleby, Charles James, Messrs. Appleby Brothers, 89 Cannon Street, London, E.C. [*Millwright, London.* 1731.]; and East Greenwich Works, London, S.E.

1874. Aramburu y Silva, Fernando, Messrs. Aramburu and Sons, Cartridge Manufacturers, Calle de la Virgen de las Azucenas, Madrid: (or care of Manuel Cardenosa, 86 Great Tower Street, London, E.C.)

1881. Archbold, Joseph Gibson, Messrs. Fawcett Preston and Co., Phœnix Foundry, 17 York Street, Liverpool; and 176 Upper Parliament Street, Liverpool.

1874. Archer, David, Central Chambers, Corporation Street, Birmingham; and 275 Pershore Road, Birmingham.

1883. Arens, Henrique, Messrs. Arens and Irmaos, Engineering Works, Rio de Janeiro, Brazil: (or care of Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.)

1882. Armer, James, Messrs. J. and E. Hall, Iron Works, Dartford. [*Armer, Hallford, Dartford;* or *Armer, Sidcup.*]

1859. Armitage, William James, Farnley Iron Works, Leeds.

1879. Armstrong, Alexander, Melrose, North Shore, Auckland, New Zealand.

1866. Armstrong, George, Great Western Railway, Locomotive Department, Stafford Road Works, Wolverhampton.

1882. Armstrong, George Frederick, Professor of Engineering, The University, Edinburgh.

1876. Armstrong, William, Jun., Mining Engineer, Wingate Colliery, County Durham.

1858. Armstrong, Sir William George, C.B., D.C.L., LL.D., F.R.S., Elswick, Newcastle-on-Tyne; and Cragside, Morpeth.

1870. Armstrong, William Irving, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

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1873. Arnold, David Nelson, Messrs. Willans Arnold and Co., Spanish Steel Works, Sheffield.

1879. Arrol, Thomas Arthur, Messrs. Arrol Brothers, Germiston Iron Works, Glasgow; and 18 Blythswood Square, Glasgow.

1873. Ashbury, Thomas (*Life Member*), 28A Market Street, Manchester. [*Thomas Ashbury, Manchester.*]

1884. Ashwell, Frank, 10 Erskine Street, Leicester.

1881. Aspinall, John Audley Frederick, Locomotive Superintendent, Great Southern and Western Railway, Dublin.

1877. Astbury, James, Smethwick Foundry, near Birmingham.

1870. Atkinson, Charles Fanshawe, Messrs. Marriott and Atkinson, Fitzalan Steel Works, Sheffield. [*Marriott's, Sheffield.* 174.]

1875. Atkinson, Edward (*Life Member*), care of Messrs. Mackenzie and Brougham, 15 Great George Street, Westminster, S.W.

1882. Aveling, Thomas Lake, Messrs. Aveling and Porter, Rochester.

1879. Bagot, Alan Charles, care of Edward W. Bowles, 86 Cambridge Street, London, S.W.

1872. Bagshaw, Walter, Messrs. J. Bagshaw and Sons, Victoria Foundry, Batley. [*Bagshaw, Batley.*]

1865. Bailey, John, Villa des Arts, Boulogne-sur-mer, France.

1885. Bailey, William Henry, Albion Works, Salford, Manchester.

1880. Baillie, Robert, Messrs. Westwood Baillie and Co., London Yard Iron Works, Poplar, London, E.

1872. Bailly, Philimond, 62 Rue de la Victoire, Paris.

1880. Bain, William Neish, Messrs. Kyle and Bain, Hong Kong Ice Works, Eastpoint, Hong Kong, China; and Collingwood, 7 Aytoun Road, Pollockshields, Glasgow.

1873. Baird, George, St. Petersburg; and 13 Berkeley Square, London, W.

1875. Bakewell, Herbert James, Engineer, Department of the Controller of the Navy, Admiralty, Whitehall, London, S.W.

1877. Bale, Manfred Powis, Appold Street, Finsbury, London, E.C.

1881. Balmokand, Lala, Assistant Engineer, Public Works Department, Punjaub, India; care of Lala Shamba Das, Said Mitha, Lahore, India.

1879. Banderali, David, Assistant Locomotive and Carriage Superintendent, Chemin de fer du Nord, Paris.

1870. Barber, Thomas, Mining Engineer, High Park Collieries, Eastwood, Nottinghamshire.

1870. Barclay, Arthur, Westfield, Surbiton, R.O., Kingston-on-Thames.

1885. Barker, Tom Birkett, Scholefield Street, Birmingham.

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1884. Barlow, Elias, Messrs. William Muir and Co., Britannia Works, Sherborne Street, Strangeways, Manchester.

1882. Barlow, Henry Bernoulli, Cornbrook Heald Works, Chester Road, Manchester. [*Monopoly, Manchester.*]

1875. Barlow, William Henry, F.R.S., 2 Old Palace Yard, Westminster, S.W.

1880. Barlow-Massicks, Thomas, Millom Iron Works, Millom, Cumberland.

1881. Barnett, John Davis, Mechanical Superintendent, Midland Railway, Port Hope, Ontario, Canada.

1884. Barr, Archibald, Professor of Engineering, Yorkshire College, Leeds.

1878. Barr, James, Calside Villa, Paisley.

1883. Barras, Harry Haywood, Locomotive Superintendent, Southern Brazilian Rio Grande do Sul Railway, Rio Grande do Sul, Brazil; (or care of George Thomas Barras, 7 Howard Street, Rotherham.)

1879. Barratt, Samuel, Engineer and Manager, Corporation Gas Works, Rochdale Road Station, Manchester.

1882. Barrett, John James, Sewlal Motilal Cotton Mill, Tardeo, Bombay.

1885. Barrie, William, Outside Superintendent Engineer, Nippon Yusen Kaisha Steam Ship Co., Yokohama, Japan.

1862. Barrow, Joseph, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]

1867. Barrows, Thomas Welch, Messrs. Barrows and Stewart, Portable Engine Works, Banbury. [*Barrows, Banbury.*]

1871. Barry, John Wolfe, 23 Delahay Street, Westminster, S.W. [*Wolfebarry, London.* 3024.]

1883. Bartlett, James Herbert, Standard Building, Montreal, Canada.

1883. Bastin, Edwin Philp, Alliance Engineering Works, West Drayton, near Uxbridge.

1860. Batho, William Fothergill, 9 Victoria Chambers, Victoria Street, Westminster, S.W. [*Othniel, London.* 3138.]

1881. Bawden, William, Assistant Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1872. Bayliss, Thomas Richard, Adderley Park Rolling Mills and Metal Works, Birmingham; and Belmont, Northfield, Birmingham.

1877. Beale, William Phipson, 12 Old Square, London, W.C.; and 19 Upper Phillimore Gardens, Kensington, London, W.

1881. Beattie, Alfred Luther, Manager, New Zealand Railway Workshops, Dunedin, Otago, New Zealand.

1882. Beattie, Frank, Queen Chambers, 88 Colmore Row, Birmingham.

1880. Beaumont, William Worby, 163 Strand, London, W.C.

1859. Beck, Edward (*Life Member*), Dallam Forge, Warrington; and 21 Bold Street, Warrington.

1873. Beck, William Henry, 115 Cannon Street, London, E.C.

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1875. Beckwith, John Henry, Manager, Messrs. W. and J. Galloway and Sons, Knott Mill Iron Works, Manchester.

1882. Bedson, Joseph Phillips, Messrs. Richard Johnson and Nephew, Bradford Iron Works, Manchester.

1875. Beeley, Thomas, Engineer and Boiler Maker, Hyde Junction Iron Works, Hyde, near Manchester.

1884. Beetlestone, George John, 94 St. Mary Street, Cardiff.

1885. Bell, Charles Lowthian, Clarence Iron Works, Middlesbrough.

1858. Bell, Sir Lowthian, Bart., F.R.S., Clarence Iron Works, Middlesbrough; Rounton Grange, Northallerton; Reform Club, Pall Mall, London, S.W.; and care of the Hon. E. Lyulph Stanley, 82 Harley Street, London, W. [*Sir Lowthian Bell, Middlesbrough.*]

1880. Bell, William Henry, Bolivia: care of Sir W. G. Armstrong Mitchell and Co., 8 Great George Street, Westminster, S.W.

1879. Bellamy, Charles James, 38 Parliament Street, Westminster, S.W.

1868. Belliss, George Edward, Steam Engine and Boiler Works, Ledsam Street, Birmingham.

1878. Belsham, Maurice, Messrs. Price and Belsham, 52 Queen Victoria Street, London, E.C.

1880. Benham, Percy, Messrs. Benham, 66 Wigmore Street, London, W. [*Benham, London.* 7065.]

1854. Bennett, Peter Duckworth, Horseley Iron Works, Tipton.

1878. Berrier-Fontaine, Marc, Ingénieur de la Marine, Toulon Dockyard, Toulon, France: (or care of Messrs. P. S. King and Son, Canada Buildings, King Street, Westminster, S.W.) [*Berrier, Toulon.*]

1861. Bessemer, Sir Henry, F.R.S., Denmark Hill, London, S.E.

1866. Bevis, Restel Ratsey, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead; and Manor Hill, Birkenhead.

1874. Bewick, Thomas John, Mining Engineer, Suffolk House, Laurence Pountney Hill, London, E.C.

1870. Bewlay, Hubert, Birmingham Heath Boiler Works, Spring Hill, Birmingham.

1882. Bewley, Thomas Arthur, Messrs. Bewley Webb and Co., Port of Dublin Ship Yard, Dublin.

1885. Bicknell, Arthur Channing, Sandycroft Foundry, Chester.

1883. Bicknell, Edward, Locomotive Superintendent, La Guaira and Caracas Railway, Venezuela; and 8 Canynge Square, Clifton, Bristol.

1884. Bika, Léon Joseph, Locomotive Engineer-in-Chief, Belgian State Railway, 29 Rue des Palais, Bruxelles.

1877. Birch, Robert William Peregrine, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1847. Birley, Henry, 6 Brentwood, Pendleton, R.O., Manchester.

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1875. Bisset, William Harvey, Board of Trade Office, Falmouth; and Erin Lodge, Green Bank, Falmouth.

1879. Black, William, Messrs. Black Hawthorn and Co., Gateshead.

1862. Blake, Henry Wollaston, F.R.S., Messrs. James Watt and Co., 90 Leadenhall Street, London, E.C.

1881. Blechynden, Alfred, Rio Tinto Mines, Huelva, Spain.

1867. Bleckly, John James, Bewsey Iron Works, Warrington; and Daresbury Lodge, Altrincham.

1882. Blundstone, Samuel Richardson, 2 Victoria Mansions, Victoria Street, Westminster, S.W.

1881. Bocquet, William, Locomotive Engineer, Scinde Punjaub and Delhi Railway, Lahore, India.

1883. Bodden, George, Messrs. William Bodden and Son, Hargreaves Spindle and Flyer Works, Oldham.

1863. Boeddinghaus, Julius, Electrotechniker, Düsseldorf, Germany.

1884. Bone, William Lockhart, Works of the Ant and Bee, West Gorton, Manchester.

1880. Borodin, Alexander, Engineer-in-Chief, Russian South Western Railways, Kieff, Russia.

1885. Boughton, Henry Francis, Dan Rylands, Glass Works, Barnsley.

1878. Bourdon, François Edouard, 74 Faubourg du Temple, Paris: (or care of Messrs. Negretti and Zambra, Holborn Viaduct, London, E.C.)

1884. Bourne, James Johnstone, Abberley, Wallington, Surrey.

1879. Bourne, William Temple, Messrs. Bourne and Grove, Bridge Steam Saw Mills, Worcester.

1879. Bovey, Henry Taylor, Professor of Engineering, McGill University, Montreal, Canada.

1880. Bow, William, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]

1870. Bower, Anthony, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.

1858. Bower, John Wilkes (*Life Member*), Neston, near Chester.

1882. Bowie, Augustus Jesse, Jun., Mining and Hydraulic Engineer, P.O. Drawer 2220, San Francisco, California, United States.

1869. Boyd, William, Wallsend Slipway and Engineering Works, Wallsend, near Newcastle-on-Tyne. [*Wall, Newcastle-on-Tyne; Wall, Cardiff.*]

1884. Boyer, Robert Skeffington, Pier Head Chambers, Cardiff.

1882. Bradley, Frederic, Clensmore Foundry, Kidderminster.

1878. Bradley, Frederick Augustus, 39 Queen Victoria Street, London, E.C.

1881. Bradley, Thomas, Wellington Foundry, Newark.

1878. Braithwaite, Charles C., 35 King William Street, London Bridge, London, E.C.

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1875. Braithwaite, Richard Charles, Norfolk House, Handsworth, R. O., Birmingham. [*Braithwaite, Westbromwich.*]

1854. Bramwell, Sir Frederick Joseph, F.R.S., 5 Great George Street, Westminster, S.W. [*Wellbram, London.* 3060.]

1885. Brearley, Benjamin J., Ravenhead Plate Glass Works, Ravenhead, St. Helen's.

1868. Breeden, Joseph, New Mill Works, Fazeley Street, Birmingham.

1883. Bricknell, Augustus Lea, Merlin Engineering Works, Brixton Rise, London, S.W.

1881. Briggs, John Henry, Howden.

1880. Bright, Thomas Smith, 1 Northampton Villas, St. Helen's Road, Swansea.

1865. Brock, Walter, Messrs. Denny and Co., Engine Works, Dumbarton.

1879. Brodie, John Shanks, Town Surveyor and Harbour Engineer, Town Hall, Whitehaven.

1852. Brogden, Henry (*Life Member*), Hale Lodge, Altrincham, near Manchester.

1884. Brook-Fox, Frederick George, Executive Engineer, Bellary Kistna State Railway, Cumbum, Madras Presidency, India.

1880. Brophy, Michael Mary, Messrs. James Slater and Co., 251 High Holborn, London, W.C.

1874. Brotherhood, Peter, 15 and 17 Belvedere Road, Lambeth, London, S.E.; and 94 Cromwell Road, South Kensington, London, S.W.

1866. Brown, Andrew Betts, Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.

1885. Brown, Benjamin, Widnes Foundry, Widnes.

1879. Brown, Charles, Manager, Maschinenfabrik, Oerlikon, Switzerland: (or care of Dr. Gardiner Brown, 9 St. Thomas' Street, London Bridge, London, S.E.)

1880. Brown, Francis Robert Fountaine, Mechanical Superintendent, Canadian Pacific Railway, Montreal, Canada.

1881. Brown, George William, Reading Iron Works, Reading.

1863. Brown, Henry, Waterloo Chambers, Waterloo Street, Birmingham.

1884. Brown, Oswald, 27 Great George Street, Westminster, S.W. [*Acqua, London.* 3054.]

1874. Browne, Tomyns Reginald, Assistant District Locomotive Superintendent, East Indian Railway, Allahabad, India: (or care of Messrs. B. Smyth and Co., 1 New China Bazaar Street, Calcutta.)

1874. Bruce, George Barclay, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1867. Bruce, William Duff, Vice-Chairman, Port Commission, Calcutta.

1873. Brunel, Henry Marc, 23 Delahay Street, Westminster, S.W. [3024.]

1870. Brunlees, James, F.R.S.E., 5 Victoria Street, Westminster, S.W.

1884. Bryan, William B., Engineer, East London Water Works, Old Ford, London, E.

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1873. Buckley, Robert Burton, Executive Engineer, Indian Public Works Department, Writers' Buildings, Calcutta: (or care of H. Burton Buckley, 1 St. Mary's Terrace, Paddington, London, W.)

1877. Buckley, Samuel, Messrs. Buckley and Taylor, Castle Iron Works, Oldham.

1878. Buddicom, Harry William, Moreton Villa, Abergavenny.

1874. Buddicom, William Barber, Penbedw Hall, Mold, Flintshire.

1872. Budenberg, Arnold, Messrs. Schaeffer and Budenberg, 1 Southgate, St. Mary's Street, Manchester. [*Manometer, Manchester.* 899.]

1882. Budge, Enrique, Engineer-in-Chief, Harbour Works, Valparaiso, Chile.

1881. Bulkley, Henry Wheeler, 149 Broadway, New York.

1884. Bullock, Joseph Henry, General Manager, Pelsall Coal and Iron Works, near Walsall.

1882. Bulmer, John, Spring Garden Engineering Works, Pitt Street, Newcastle-on-Tyne.

1884. Bunning, Charles Ziethen, Mining Engineer of the Government Coal Mines, Warora, Central Provinces, India.

1884. Bunt, Thomas, Superintendent Engineer, Kiangnan Arsenal, Shanghai, China: (or care of R. Pearce, Lanarth House, Holders Hill, Hendon, London, N.W.)

1884. Bunting, George Albert, Rio Tinto Mines, Huelva, Spain.

1885. Burder, Walter Chapman, Messrs. Messenger and Co., Loughborough.

1877. Burgess, James Fletcher, 14 Almeric Road, Clapham Junction, London, S.W.

1881. Burn, Robert Scott, Oak Lea, Edgeley Road, near Stockport.

1874. Burn, William Edward, Ashleigh Villa, Willow Brae Road, Edinburgh.

1878. Burnett, Robert Harvey, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1878. Burrell, Charles, Jun., Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford.

1885. Burrell, Frederick John, Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford.

1877. Burton, Clerke, 22 Oakfield Street, Roath, Cardiff.

1870. Bury, William, 5 New London Street, London, E.C.

1884. Butcher, Joseph John, 4 St. Nicholas' Buildings, Newcastle-on-Tyne.

1882. Butler, Edmund, Kirkstall Forge, near Leeds.

1877. Campbell, Angus, Superintendent of the Government Foundry and Workshops, Roorkee, India.

1880. Campbell, Daniel, Messrs. Campbell and Schultz, 90 Cannon Street, London, E.C. [*Duke, London.* 1893.]

1869. Campbell, James, Hunslet Engine Works, Leeds.

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1882. Campbell, John, Messrs. R. W. Deacon and Co., Kalimaas Works, Soerabaya, Java.

1885. Capito, Charles Alfred Adolph, Messrs. Capito and Hardt, Metropolitan Buildings, 63 Queen Victoria Street, London, E.C.; and 7 Nygade, Copenhagen. [*Capito Hardt, London.*]

1860. Carbutt, Edward Hamer, M.P., 19 Hyde Park Gardens, London, W.

1878. Cardew, Cornelius Edward, Locomotive and Carriage Superintendent, State Railways Establishment, Public Works Department, Government of India: care of Messrs. King King and Co., Bombay: (or care of Rev. J. H. Cardew, Keynshambury House, Cheltenham.)

1875. Cardozo, Francisco Corrêa de Mesquita (*Life Member*), Messrs. Cardozo and Irmão, Pernambuco Engine Works, Pernambuco, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

1878. Carlton, Thomas William, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C. [1618.]; and 1 Canfield Gardens, Priory Road, West Hampstead, London, N.W.

1869. Carpmael, Frederick, 57 Arlingford Road, Tulse Hill Gardens, Brixton, London, S.W.

1866. Carpmael, William, 24 Southampton Buildings, London, W.C. [*Carpmael, London.* 2608.]

1877. Carr, Robert, Resident Engineer, London and St. Katharine Docks Co., London Docks, Upper East Smithfield, London, E.

1884. Carrick, Henry, Messrs. Carrick and Wardale, Redheugh Engine Works, Gateshead; and Holly House, Gateshead.

1874. Carrington, William T. H., 9 and 11 Fenchurch Avenue, London, E.C.

1877. Carter, Claude, Manager, Messrs. Hetherington and Co., Ancoats Works, Pollard Street, Manchester.

1885. Carter, Herbert Fuller, Rio Tinto Mines, Huelva, Spain.

1877. Carter, William, Ingénieur-en-Chef, Société anonyme du Phœnix, Ghent, Belgium.

1870. Carver, James, Lace Machine Works, Alfred Street, Nottingham.

1883. Cawley, George, Assistant Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1876. Challen, Stephen William, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham.

1884. Chamberlain, John, Assistant Engineer, Gas Light and Coke Co.'s Tar and Liquor Works, Beckton, London, E.

1882. Chapman, Hedley, Messrs. Chapman Carverhill and Co., Scotswood Road, Newcastle-on-Tyne.

1866. Chapman, Henry, 113 Victoria Street, Westminster, S.W.; and 10 Rue Laffitte, Paris.

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1878. Chapman, James Gregson, Messrs. Fawcett Preston and Co., Phœnix Foundry, Liverpool; and 25 Austinfriars, London, E.C. [*Fawcett, London.*]

1885. Chapman, John, Engineer, Windsor and Eton Water Works, Eton.

1885. Charnock, George Frederick, Engineering Department, Technical College, Bradford.

1877. Chater, John, Messrs. Henry Pooley and Son, 89 Fleet Street, London, E.C.

1872. Chatwin, Thomas, Victoria Works, Great Tindal Street, Ladywood, Birmingham.

1873. Cheesman, William Talbot, Hartlepool Rope Works, Hartlepool.

1881. Chilcott, William Winsland, Devonport Dockyard, Devonport.

1883. Childe, Rowland, Mining Engineer, Stamp Office Place, Wakefield.

1877. Chisholm, John, Messrs. William Muir and Co., Sherborne Street, Manchester; and 30 Devonshire Street, Higher Broughton, Manchester.

1857. Chrimes, Richard, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1880. Churchward, George Dundas, Box 717, General Post Office, Sydney, New South Wales; or care of A. W. Churchward, London Chatham and Dover Railway, Queenborough Pier, Queenborough; and Kersney Manor, Dover.

1871. Clark, Christopher Fisher, Mining Engineer, Garswood Coal and Iron Co., Park Lane Collieries, Wigan; and Cranbury Lodge, Park Lane, Wigan. [*Park Lane, Wigan.*]

1878. Clark, Daniel Kinnear, 8 Buckingham Street, Adelphi, London, W.C.

1859. Clark, George, Sen., Southwick Engine Works, near Sunderland (*deceased*).

1867. Clark, George, Southwick Engine Works, near Sunderland.

1869. Clark, William, Mining Engineer, Teversall Collieries, near Mansfield.

1865. Clarke, John, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds. [*Loco, Leeds.* 504.]

1869. Clarke, William, Messrs. Clarke Chapman and Gurney, Victoria Works, South Shore, Gateshead.

1870. Clayton, Nathaniel, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.

1882. Clayton, William Wikeley, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds.

1871. Cleminson, James, 7 Westminster Chambers, Victoria Street, Westminster, S.W. [*Cleminson, London.* 3046.]

1873. Clench, Frederick, Messrs. Robey and Co., Globe Iron Works, Lincoln. [*Robey, Lincoln.*]

1885. Close, John, Jun., York Engineering Works, Leeman Road, York.

1885. Clutterbuck, Herbert, 3 Westbourne Grove, Coatham, R.O., Redcar.

1882. Coates, Joseph, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1883. Coath, David Decimus, Agricultural Implement Works and Saw Mill, Rangoon, British Burmah, India.

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1881. Cochrane, Brodie, Mining Engineer, Aldin Grange, Durham.

1858. Cochrane, Charles, Woodside Iron Works, near Dudley; and The Grange, Stourbridge.

1885. Cochrane, John, Grahamston Foundry and Engine Works, Barrhead, near Glasgow.

1869. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.

1868. Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne; and Oakfield House, Gosforth, Newcastle-on-Tyne.

1867. Cockey, Francis Christopher, Selwood Iron Works, Frome.

1864. Coddington, William, M.P., Ordnance Cotton Mill, Blackburn; and Wycolla, Blackburn.

1876. Coe, William John, 1 Rumford Place, Liverpool.

1847. Coke, Richard George, Mining Engineer, 39 Holywell Street, Chesterfield; and Brimington Hall, near Chesterfield.

1884. Cole, Charles, Messrs. Cole Marchent and Co., Prospect Foundry, Bowling, near Bradford.

1878. Cole, John William, Elm Cottage, Osmond Terrace, Norwood, Adelaide, South Australia: (or care of Messrs. James Sinton and Co., 7 St. Benet Place, Gracechurch Street, London, E.C.)

1878. Coles, Henry James, Sumner Street, Southwark, London, S.E.

1877. Coley, Henry, Mansion House Chambers, Queen Victoria Street, London, E.C.

1884. Collenette, Ralph, Hæmatite Iron and Steel Works, Barrow-in-Furness.

1884. Colquhoun, James, General Manager, Tredegar Iron Coal and Steel Works, Tredegar.

1884. Coltman, John Charles, Messrs. Huram Coltman and Son, Engineering Works, Meadow Lane, Loughborough.

1878. Colyer, Frederick, 18 Great George Street, Westminster, S.W.

1881. Compton-Bracebridge, John Edward, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.

1874. Conyers, William, Engineer, Bluff Harbor Board, Campbelltown, Otago, New Zealand.

1877. Cooper, Arthur, North Eastern Steel Co., Royal Exchange, Middlesbrough.

1883. Cooper, Charles Friend, Messrs. Paterson and Cooper, Telegraph Works, Pownall Road, Dalston, London, E. [*Patella, London.* 1140.]

1877. Cooper, George, Engineer and General Manager, Buenos Aires Great Southern Railway, Buenos Aires: (or care of Secretary, Buenos Aires Great Southern Railway, 4 Great Winchester Street, London, E.C.)

1874. Cooper, William, Neptune Foundry, Hull.

1881. Coote, Arthur, Messrs. R. and W. Hawthorn Leslie and Co., Hebburn, Newcastle-on-Tyne.

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1881. Copeland, Charles John, Messrs. Westray Copeland and Co., Barrow-in-Furness.

1885. Coppée, Evence, 223 Avenue Louise, Brussels.

1884. Corder, George Alexander, Chief Engineer, Chinese Naval Service, Amoy, China; care of Commissioner of Customs, Amoy, China.

1878. Cornes, Cornelius, 6 Norfolk Crescent, Bath, [*Stothert, Cornes, Bath.*]; and 30 Walbrook, London, E.C. [*Stothert, Cornes, London.*]

1848. Corry, Edward, 9 New Broad Street, London, E.C.

1881. Cosser, Thomas, McLeod Road Iron Works, Kurrachee, India.

1875. Cotton, Francis Michael, Metropolitan Board of Works, Spring Gardens, London, S.W.

1884. Cotton, John, Messrs. E. Ripley and Sons, Bowling Dye Works, Bradford.

1875. Cottrill, Robert Nivin, Beehive Works, Bolton.

1868. Coulson, William, Mining Engineer, 32 Crossgate, Durham; and Shamrock House, Durham.

1878. Courtney, Frank Stuart, 3 Whitehall Place, London, S.W.

1882. Courtney, William McDougall, 15 Elizabeth Terrace, Upper William Street North, Sydney, New South Wales.

1875. Coward, Edward, Messrs. Melland and Coward, Cotton Mills and Bleach Works, Heaton Mersey, near Manchester.

1875. Cowen, Edward Samuel, Messrs. G. R. Cowen and Co., Beck Foundry, Brook Street, Nottingham; and 9 Rope Walk Street, Nottingham.

1870. Cowen, George Roberts, Messrs. G. R. Cowen and Co., Beck Foundry, Brook Street, Nottingham; and 9 Rope Walk Street, Nottingham.

1880. Cowper, Charles Edward, 6 Great George Street, Westminster, S.W.

1847. Cowper, Edward Alfred, 6 Great George Street, Westminster, S.W.

1878. Coxhead, Frederick Carley, 27 Leadenhall Street, London, E.C.

1883. Crampton, George, 4 Victoria Street, Westminster, S.W.

1847. Crampton, Thomas Russell, 4 Victoria Street, Westminster, S.W.

1882. Craven, John, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.

1871. Craven, Joseph, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.

1866. Craven, William, Vauxhall Iron Works, Osborne Street, Manchester.

1884. Crighton, John, Messrs. J. and R. Crighton, Helena Street, Ancoats, Manchester.

1873. Crippin, Edward Frederic, Mining Engineer, Brynn Hall Colliery, Ashton, near Wigan.

1883. Croft, Henry, Chemanns, Vancouver Island.

1878. Crohn, Frederick William, 16 Burney Street, Greenwich, S.E.

1877. Crompton, Rookes Evelyn Bell, Arc Works, Chelmsford; and Mansion House Buildings, Queen Victoria Street, London, E.C.

1884. Crook, Charles Alexander, Telegraph Construction and Maintenance Works, Enderby's Wharf, East Greenwich, London, S.E.

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1883. Cropper, Henry S., Minerva Works, Alfred Street North, Nottingham.
1881. Crosland, James Foyell Lovelock, Chief Assistant Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.
1865. Cross, James, Messrs. John Hutchinson and Co., Alkali Works, Widnes; and Ditton Lodge, Warrington.
1882. Cross, William, Messrs. R. and W. Hawthorn Leslie and Co., St Peter's Works, Newcastle-on-Tyne.
1871. Crossley, William, 153 Queen Street, Glasgow. [*Crossley, Glasgow.* 584.]
1875. Crossley, William John, Messrs. Crossley Brothers, Great Marlborough Street, Manchester.
1882. Cruickshank, William Douglass, Chief Government Engineer Surveyor, Marine Board, Sydney, New South Wales.
1884. Cureton, Barnard John, Manager, Patent Nut and Bolt Works, Smethwick, near Birmingham.
1875. Curtis, Richard, Messrs. Curtis Sons and Co., Phœnix Works, Chapel Street, Manchester.
1876. Cutler, Samuel, Providence Iron Works, Millwall, London, E. [*Cutler, Millwall.* 5059.]

1879. Dady, Jamsetjee Nesserwanjee, 10 Dady Sett House, Fort, Bombay, India.
1864. Daglish, George Heaton, St. Helen's Foundry, St. Helen's, Lancashire. [*Daglish, St. Helen's.*]
1883. D'Albert, Charles, Messrs. Hotchkiss and Co., 6 Route de Gonesse, St. Denis, near Paris; and 16 Rue des Chesneaux, Montmorency, Seine-et-Oise, France.
1881. D'Alton, Patrick Walter, London Mutual Boiler Insurance Co., 17 Queen Victoria Street, London, E.C.
1866. Daniel, Edward Freer, Messrs. Worthington and Co., The Brewery, Burton-on-Trent; and 89 Derby Street, Burton-on-Trent.
1866. Daniel, William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds; and Oxford House, Horsforth, Leeds.
1878. Darwin, Horace (*Life Member*), The Orchard, Huntingdon Road, Cambridge.
1873. Davey, Henry, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds.
1883. Davidson, George, Superintendent Engineer, Australasian Steam Navigation Co., Sydney, New South Wales.
1865. Davidson, James, Laboratory Department, Royal Arsenal, Woolwich.
1881. Davidson, James, Engineering Works, Cumberland Street, Dunedin, Otago, New Zealand: (or care of Messrs. Buxton Ronald and Co., 24 Basinghall Street, London, E.C.)

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1884. Davidson, James Young, Manager, Nagpur and Chhattisgarh, and Wardha Coal State Railways, Nagpur, Central Provinces, India; (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)

1884. Davies, Alfred Herbert, Eskell Chambers, Market Place, Nottingham.

1881. Davies, Benjamin, Bleach Works, Adlington, near Chorley.

1880. Davies, Charles Merson, Locomotive Superintendent, Nagpur and Chhattisgarh State Railway, Nagpur, Central Provinces, India.

1885. Davies, Edward John Mines, 82 Kingsdown Parade, Bristol.

1874. Davis, Alfred, Parliament Mansions, Westminster, S.W.

1868. Davis, Henry Wheeler, 38 New Broad Street, London, E.C.

1873. Davis, John Henry, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester; and 147 Cannon Street, London, E.C.

1877. Davison, John Walter, 1 Meshansky, Banny pereoulok, Moscow, Russia: (or care of Alfred L. Sacré, 60 Queen Victoria Street, London, E.C.)

1884. Davison, Robert, Caledonian Railway, Locomotive Department, St. Rollox, Glasgow.

1873. Davy, David, Messrs. Davy Brothers, Park Iron Works, Sheffield.

1874. Davy, Walter Scott, Hæmatite Iron and Steel Works, Barrow-in-Furness.

1883. Daw, James Gilbert, Messrs. Nevill Druce and Co., Llanelly Copper Works, Llanelly.

1874. Daw, Samuel, Ivy Tor, 15 Westhouse Road, Penarth.

1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.

1879. Dawson, Bernard, 110 Cannon Street, London, E.C. [*Crocus, London.*]; and The Laurels, Malvern Link, Malvern. [*Heather, Malvern Link.*]

1869. Day, St. John Vincent, 115 St. Vincent Street, Glasgow.

1874. Deacon, George Frederick, Municipal Offices, Dale Street, Liverpool.

1880. Deacon, Richard William, Boeboetan, Clive Road, Penarth.

1883. Dean, Francis Winthrop, East Taunton, Massachusetts, United States.

1868. Dean, William, Locomotive Superintendent, Great Western Railway, Swindon. [*Loco, Swindon.*]

1866. Death, Ephraim, Messrs. Death and Ellwood, Albert Works, Leicester.

1884. Decauville, Paul, Portable Railway Works, Petit Bourg, Seine et Oise, France.

1877. Dees, James Gibson, 36 King Street, Whitehaven.

1858. Dempsey, William, 26 Great George Street, Westminster, S.W.

1882. Denison, Samuel, Jun., Messrs. Samuel Denison and Son, Old Grammar School Foundry, North Street, Leeds. [*Weigh, Leeds.* 221.]

1883. Dennis, William Frederick, 101 Leadenhall Street, London, E.C. [*Fredennis, London.* 559.]

1882. Denny, William, F.R.S.E., Messrs. William Denny and Sons, Leven Ship Yard, Dumbarton. [*Denny, Dumbarton.*]

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1880. De Pape, William Alfred Harry, Tottenham Board of Health, Coombes Croft House, High Road, Tottenham, Middlesex.

1883. Dick, Frank Wesley, Steel Company of Scotland, Blochairn Steel Works, Glasgow.

1882. Dick, Gavin Gemmell, 1 Westminster Chambers, Victoria Street, Westminster, S.W.

1880. Dickinson, John, Palmer's Hill Engine Works, Sunderland. [*Bede, Sunderland.*]

1875. Dickinson, William, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.

1879. Dickson, John, Willowbank, Darlington.

1883. Dixon, Samuel, Messrs. Kendall and Gent, Victoria Works, Springfield, Salford, Manchester.

1872. Dobson, Benjamin Alfred, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton. [*Dobsons, Bolton.*]

1873. Dobson, Richard Joseph Caistor, Suiker Fabriek, Kalibayor, Banjoemas, Java: (or care of Charles E. S. Dobson, 4 Chesterfield Buildings, Victoria Park, Clifton, Bristol.)

1880. Dodd, John, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1868. Dodman, Alfred, Highgate Foundry, Lynn. [*Dodman, Lynn.*]

1880. Donald, James, Messrs. Donald Henesey and Couper, Ripon Iron Works, Frere Road, Bombay: (or care of Messrs. Fleming Wilson and Co., 24, 25, 27 Rood Lane, Fenchurch Street, London, E.C.)

1876. Donaldson, John, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.; and Tower House, Turnham Green.

1873. Donkin, Bryan, Jun., Messrs. B. Donkin and Co., Blue Anchor Road, Bermondsey, London, S.E.

1884. Donnelly, John, Assistant Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.W.; and 70 Studley Road, Clapham Road, London, S.W.

1865. Douglas, Charles Prattman, Consett Iron Works, near Blackhill, County Durham; and Parliament Street, Consett, County Durham.

1879. Douglass, Sir James Nicholas, Trinity House, London, E.C. [2242.]

1879. Douglass, William, Chief Engineer to the Commissioners of Irish Lights, Westmoreland Street, Dublin.

1879. Doulton, Bernard, Lambeth Pottery, Lambeth, London, S.E.

1857. Dove, George, Messrs. Cowans Sheldon and Co., St. Nicholas Engine and Iron Works, Carlisle; and Viewfield, Stanwix, near Carlisle.

1873. Dove, George, Jun., Redbourn Hill Iron and Coal Co., Frodingham, near Doncaster. [*Redbourn, Frodingham.*]

1866. Downey, Alfred C., Messrs. Downey and Co., Coatham Iron Works, Middlesbrough; and Post Office Chambers, Middlesbrough.

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1881. Dowson, Joseph Emerson, 3 Great Queen Street, Westminster, S.W.
1880. Doxford, Robert Pile, Messrs. William Doxford and Sons, Pallion Shipbuilding and Engine Works, Sunderland.
1874. Dredge, James, 35 Bedford Street, Strand, London, W.C.
1877. Dübs, Charles Ralph, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.
1877. Dübs, Henry John Sillars, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.
1885. Duckering, Charles, Water Side Works, Rosemary Lane, Lincoln.
1880. Duckham, Frederic Eliot, Engineer, Millwall Docks, London, E.
1881. Duckham, Heber, 184 Lewisham Road, London, S.E. [*Duckham, London.*]
1879. Duncan, David John Russell, Messrs. Duncan Brothers, 32 Queen Victoria Street, London, E.C. [*Doucine, London.*]; and 10 Airlie Gardens, Kensington, London, W.
1870. Dunlop, James Wilkie, 49 Albert Street, Regent's Park, London, N.W.
1881. Dunn, Henry Woodham, Knysna, Cape Colony.
1885. Durham, Frederick William, 23 Leadenhall Street, London, E.C. [*Oilring, London.*]
1865. Dyson, Robert, Messrs. Owen and Dyson, Rother Iron Works, Rotherham.

1880. Eager, John Edward, Messrs. William Crichton and Co., Engineering and Shipbuilding Works, Abo, Finland.
1869. Earnshaw, William Lawrence, Superintending Marine Engineer, South Eastern Railway, Folkestone.
1858. Easton, Edward, 11 Delahay Street, Westminster, S.W.
1884. Eastwood, Charles, Manager, Linacre Gas Works, Liverpool.
1875. Eaves, William, Engineer, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.
1878. Eckart, William Roberts, Messrs. Salkeld and Eckart, 632 Market Street, P. O. Box 1587, San Francisco, California, United States.
1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.
1883. Edmiston, James Brown, Marine Superintending Engineer, Messrs. Hamilton Fraser and Co., K Exchange Buildings, Liverpool; and Ivy Cottage, Highfield Road, Walton, Liverpool.
1871. Edwards, Edgar James, Messrs. Morewood and Co., Woodford Iron Works, Soho, Birmingham.
1877. Edwards, Frederick, 62 Bishopsgate Street Within, London, E.C.
1880. Edwards, Robert, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.
1866. Elce, John, 9 Hopwood Avenue, Manchester.

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1879. Ellacott, Robert Henry, Messrs. Ellacott and Co., Plymouth Foundry, Plymouth. [*Ellacott, Plymouth.* 47.]

1875. Ellington, Edward Bayzand, Hydraulic Engineering Works, Chester; and Hydraulic Engineering Co., Palace Chambers, 9 Bridge Street, Westminster, S.W.

1859. Elliot, Sir George, Bart., M.P., Houghton-le-Spring, near Fence Houses.

1883. Elliott, Henry John, Assistant Manager, Elliott's Metal Works, Selly Oak, near Birmingham.

1869. Elliott, Henry Worton, Metal Sheathing Works, 10 Coleshill Street, Birmingham; and Selly Oak Works, near Birmingham.

1882. Elliott, Thomas Graham, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1880. Ellis, Oswald William, 26 George Street, Edinburgh.

1885. Elsworthy, Edward Houtson, Messrs. Richardson and Cruddas, Byculla Iron Works, Bombay, India.

1869. Elwell, Alfred, Edge Tool Works, Wood Green, Wednesbury.

1875. Elwell, Thomas, Messrs. Varrall Elwell and Middleton, 1 Avenue Trudaine, Paris.

1878. Elwin, Charles, Metropolitan Board of Works, Spring Gardens, London, S.W.

1884. Etherington, John, 39A King William Street, London Bridge, London, E.C.

1884. Evans, David, Barrow Hæmatite Steel Works, Barrow-in-Furness.

1885. Evans, Richard Kendall, Engineering Works, Sandiacre, near Nottingham.

1864. Everitt, William Edward, Messrs. Allen Everitt and Sons, Kingston Metal Works, Adderley Street, Birmingham; and Finstal, Bromsgrove.

1881. Ewen, Thomas Buttwell, Messrs. Tangye Brothers, Cornwall Works, Soho, near Birmingham.

1869. Faija, Henry, 4 Great Queen Street, Westminster, S.W.

1868. Fairbairn, Sir Andrew, M.P., Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds; and 15 Portman Square, London, W.

1875. Farcot, Jean Joseph Léon, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1880. Farcot, Paul, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1867. Fardon, Thomas, 106 Queen Victoria Street, London, E.C.; and 63 Collingdon Street, Luton.

1881. Farrar, Sidney Howard, Messrs. Howard Farrar and Co., Port Elizabeth, South Africa; and 69 Cornhill, London, E.C.

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1882. Fawcett, Thomas Constantine, Burmantofts Foundry, Leeds.
1884. Fearfield, John Piggin, Lace Machine Works, Stapleford, near Nottingham.
1882. Feeny, Victor Isidore, 106 Queen Victoria Street, London, E.C.
1876. Fell, John Corry, 1 Queen Victoria Street, London, E.C.; and Excelsior Works, Old Street, London, E.C.
1877. Fenton, James, 8 Great George Street, Westminster, S.W.
1869. Fenwick, Clennell, Victoria Docks Engine Works, Victoria Docks, London, E.
1870. Ferguson, Henry Tanner, Locomotive Superintendent, Punjaub Northern State Railway, Rawal Pindi, Punjaub, India.
1881. Ferguson, William, Harbour Board, Wellington, New Zealand: (or care of Montgomery Ferguson, 81 James Street, Dublin.)
1854. Fernie, John, P.O. Box 57, Philadelphia, Pennsylvania, United States.
1866. Fiddes, Walter, Engineer, Bristol United Gas Works, Bristol.
1872. Fidler, Edward, Prescot Colliery, Prescot.
1867. Field, Edward, Chandos Chambers, 22 Buckingham Street, Adelphi, London, W.C.
1884. Fielden, Joseph Petrie, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.
1874. Fielding, John, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester.
1884. Fisher, Henry Oakden, Engineer, Taff Vale Railway, Cardiff.
1885. Fitton, Joseph, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
1877. Flannery, James Fortescue, 9 Fenchurch Street, London, E.C. [2283.]
1864. Fleet, Thomas, Crown Boiler and Gasholder Works, Swan Village, Westbromwich.
1847. Fletcher, Edward, 2 Osborne Avenue, West Jesmond, Newcastle-on-Tyne.
1885. Fletcher, Edward, Messrs. William Collier and Co., Worsley Street, New Bailey Street, Salford, Manchester.
1883. Fletcher, George, Masson Works, Derby.
1872. Fletcher, Herbert, Ladyshore Colliery, Little Lever, Bolton; and The Hollins, Bolton.
1867. Fletcher, Lavington Evans, Chief Engineer, Manchester Steam Users' Association, 9 Mount Street, Albert Square, Manchester.
1872. Flower, James J. A., Messrs. James Flower and Sons, St. Mary's Chambers, St. Mary Axe, London, E.C. [*Floramour, London.* 551.]
1859. Fogg, Robert, 11 Queen Anne's Gate, Westminster, S.W.
1877. Forbes, Daniel Walker, Smithfield Works, New Road, Blackwall, London, E.
1882. Forbes, David Moncur, Engineer, H. M. Mint, Calcutta.
1882. Forbes, William George Loudon Stuart, Superintendent of General Workshops, H. M. Mint, Calcutta.

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1861. Forster, Edward, Messrs. Chance Brothers and Co., Glass Works, Spon Lane, near Birmingham.
1882. Forsyth, Robert Alexander, 28 Tunnel Terrace, Newport, Monmouthshire.
1884. Foster, John Slater, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.
1882. Fothergill, John Reed, Superintendent Marine Engineer, 1 Bathgate Terrace, West Hartlepool.
1877. Foulis, William, Engineer, Glasgow Corporation Gas Works, 42 Virginia Street, Glasgow.
1885. Fourny, Hector Foster, Messrs. Earle's Shipbuilding and Engineering Works, Hull.
1866. Fowler, George, Basford Hall, near Nottingham.
1847. Fowler, Sir John, K.C.M.G., 2 Queen Square Place, Westminster, S.W.
1885. Fowler, William Henry, Manchester Steam Users' Association, 9 Mount Street, Albert Square, Manchester.
1866. Fox, Charles Douglas, 2 Victoria Mansions, Victoria Street, Westminster, S.W.
1875. Fox, Samson, Leeds Forge, Leeds.
1882. Fox, William, Leeds Forge, Leeds.
1884. Frampton, Edwin, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E. [*Oxygen, London.* 8007.]
1885. Franki, James Peter, Morts Dock and Engineering Co., Morts Bay, Sydney, New South Wales: (or care of Messrs. Mort and Co., 155 Fenchurch Street, London, E.C.)
1877. Fraser, John Hazell, Messrs. Fraser Brothers, Railway Iron Works, Bromley, London, E. [*Pressure, London.* 5420.]
1876. Frost, William, Manager, Carlisle Steel and Engine Works, Sheffield; and Woodhill, Sheffield.
1866. Fry, Albert, Bristol Wagon Works, Lawrence Hill, Bristol.
1884. Furness, Edward, Metropolitan Buildings, 63 Queen Victoria Street, London, E.C.
1882. Furrell, Edward Wyburd, Exmouth.

1866. Galloway, Charles John, Messrs. W. and J. Galloway and Sons, Knott Mill Iron Works, Manchester. [*Galloway, Manchester.*]
1862. Galton, Capt. Douglas, C.B., R.E., F.R.S., 12 Chester Street, Grosvenor Place, London, S.W.
1880. Galwey, John Wilfrid de Villemont, Messrs. Galwey Whitehead and Co., Warrington Engine and Iron Works, Lythgoe's Lane, Warrington.
1884. Ganga Ram, Lala, Executive Engineer, Public Works Department, Amritsar, Punjaub, India.

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1882. Garrett, Frank, Messrs. Richard Garrett and Sons, Leiston Works, Leiston, R.S.O., Suffolk. [*Garrett, Leiston.*]

1867. Gauntlett, William Henry, 33 Albert Terrace, Middlesbrough. [*Pyrometer, Middlesbrough.*]

1880. Geoghegan, Samuel, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin.

1871. Gibbins, Richard Cadbury, Berkley Street, Birmingham.

1872. Gilbert, Ebenezer Edwin, Canada Engine Works, Montreal, Canada.

1883. Gilchrist, Percy Carlyle, Palace Chambers, 9 Bridge Street, Westminster, S.W. [*Gilchrist, London.*]

1856. Gilkes, Edgar, Messrs. Thompson and Gilkes, Stockton-on-Tees; and Ingleside, Stockton-on-Tees.

1880. Gill, Charles, Messrs. Young and Gill, Engineering Works, Java; and Java Lodge, Beckenham.

1866. Gilroy, George, Engineer, Ince Hall Colliery, Wigan.

1884. Gimson, Arthur James, Messrs. Gimson and Co., Engine Works, Vulcan Street, Leicester. [*Gimson, Leicester.* 6.]

1884. Girdlestone, John Ward, Engineer, Bristol Docks, Bristol.

1881. Girdwood, William Wallace, Indestructible Packing Works, 9 Lea Place, East India Dock Road, Poplar, London, E.

1874. Gjers, John, Messrs. Gjers Mills and Co., Ayresome Iron Works, Middlesbrough.

1862. Godfrey, Samuel, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough; and Beaconsfield House, North Ormesby, Middlesbrough.

1880. Godfrey, William Bernard, 54 Regent's Park Road, Regent's Park, London, N.W.

1882. Goldsmith, Alfred Joseph, Messrs. John Walker and Co., Union Foundry and Shipbuilding Works, Maryborough, Queensland.

1879. Goldsworthy, Robert Bruce, Messrs. Thomas Goldsworthy and Sons, Britannia Emery Mills, Hulme, Manchester.

1867. Gooch, William Frederick, Vulcan Foundry, Newton-le-Willows, Lancashire.

1884. Good, Henry, Messrs. Jardine and Co., Shanghai, China: care of Marine Engineers' Institute, Shanghai, China.

1877. Goodbody, Robert, Messrs. Goodbody, Clashawaun Jute Factory, Clara, near Moate, Ireland.

1869. Goodeve, Thomas Minchin, 5 Crown Office Row, Temple, London, E.C.

1875. Goodfellow, George Ben, Hyde Iron Works, Hyde, near Manchester.

1884. Goodger, Walter William, Messrs. Handyside and Co., Derby.

1885. Goodwin, Arnold, Jun., 56 Sumner Street, Southwark, London, S.E.

1865. Göransson, Göran Fredrick, Sandvik Iron Works, near Gefle, Sweden: (or care of F. W. Lonergan, 121 Cannon Street, London, E.C.)

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1875. Gordon, Robert, Executive Engineer, Public Works Department, Henzada, British Burmah, India: (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)

1879. Gorman, William Augustus, Messrs. Siebe and Gorman, 187 Westminster Bridge Road, London, S.E. [*Siebe, London.*]

1880. Gottschalk, Alexandre, 13 Rue Auber, Paris.

1877. Goulty, Wallis Rivers, Messrs. Wheatley Kirk, Price, and Goulty, Albert Chambers, Albert Square, Manchester. [*Indicator, Manchester.*]

1878. Grafton, Alexander, 113 Cannon Street, London, E.C.

1865. Gray, John McFarlane, Chief Examiner of Engineers, Marine Department, Board of Trade; 86 Osborn Road, Forest Gate, London, E.

1876. Gray, John William, Engineer, Corporation Water Works, Broad Street, Birmingham.

1879. Gray, Thomas Lowe, Rokesley House, St. Michael's Road, Stockwell, London, S.W.

1879. Greathead, James Henry, 8 Victoria Chambers, Victoria Street, Westminster, S.W.

1861. Green, Edward, M.P., Messrs. E. Green and Son, Phœnix Works, Wakefield.

1871. Greener, John Henry, 14 St. Swithin's Lane, London, E.C.

1878. Greenwood, Arthur, Messrs. Greenwood and Batley, Albion Works, Leeds.

1874. Greenwood, William Henry, Professor of Metallurgy and Mechanical Engineering, Firth College, Sheffield.

1865. Greig, David, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds. [*Greig, Fowler, Leeds.* 155.]

1885. Greig, David, Jun., Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1880. Gresham, James, Messrs. Gresham and Craven, Craven Iron Works, Ordsal Lane, Salford, Manchester.

1883. Grew, Frederick, 12 Stockleigh Road, St. Leonard's-on-Sea.

1874. Grew, Nathaniel, Dashwood House, 9 New Broad Street, London, E.C.

1866. Grice, Sir Edwin James, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1868. Grierson, Henry Houldsworth, Moss Brow, Warburton, near Warrington.

1884. Griffiths, James E., Mount Stuart Square, Cardiff.

1873. Griffiths, John Alfred, Priory Mill, Coventry; and 2 Chester Street, Coventry.

1879. Grose, Arthur, Manager, Vulcan Iron Works, Guildhall Road, Northampton.

1870. Guilford, Francis Leaver, Messrs. G. R. Cowen and Co., Beck Foundry, Brook Street, Nottingham.

1883. Guinotte, Lucien, Mariemont and Bascoup Collieries, Mariemont, Belgium.

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1884. Gulland, James Ker, Diamond Drill Co., 6A Victoria Street, Westminster, S.W. [*Gulland, London.*]

1870. Gwynne, James Eglinton Anderson (*Life Member*), Essex Street Works, Strand, London, W.C. [*Gwynnegram, London.*]

1870. Gwynne, John, Hammersmith Iron Works, Hammersmith, London, W.

1879. Hadfield, Robert, Hadfield Steel Foundry Co., Attercliffe, Sheffield.

1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.

1884. Hall, Albert Francis, George F. Blake Manufacturing Co., 44 Washington Street, Boston; and 3 Cordis Street, Charlestown, Boston, Massachusetts, United States.

1879. Hall, John Francis, Messrs. W. Jessop and Sons, Brightside Steel Works, Sheffield.

1881. Hall, John Percy, Engine Works Department, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow.

1882. Hall, John Willim, Foundry and Engine Works, Blaydon-on-Tyne, R.S.O., County Durham.

1874. Hall, Thomas Bernard, Patent Nut and Bolt Works, Smethwick, near Birmingham; and Ingleside, Sandon Road, Edgbaston, Birmingham.

1871. Hall, William Silver, Messrs. Hall and Clarke, Canal Street Iron Works, Derby [*Canal, Derby.*]; and 39 Hartington Street, Derby. [*Silverhall, Derby.*]

1880. Hallett, John Harry, 120 Powell's Place, Bute Docks, Cardiff.

1871. Halpin, Druitt, 9 Victoria Chambers, Victoria Street, Westminster, S.W. [*Halpin, London.*]

1870. Hamand, Arthur Samuel, 9 Bridge Street, Westminster, S.W.

1875. Hammond, Walter John, Resident Engineer and Locomotive Superintendent, Paulista Railway, Jundiahy, São Paulo, Brazil; (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

1870. Hannah, Joseph Edward, Liverpool Corporation Water Works, Llanforda Offices, Oswestry.

1874. Harding, William Bishop, Muzeum-utcza 9-ik szam, Budapest, Hungary.

1881. Hardingham, George Gatton Melhuish, 191 Fleet Street, London, E.C. [*Hardingham, London.*]

1883. Hardy, John George, Vacuum Brake Co., 7 Hohenstaufengasse, Vienna.

1869. Harfield, William Horatio, Mansion House Buildings, Queen Victoria Street, London, E.C.

1884. Harker, Harold Hayes, Locomotive Superintendent, Minas and Rio Railway, Cruzeiro, Rio de Janeiro, Brazil.

1873. Harman, Harry Jones, 22 Booth Street, Manchester.

1879. Harris, Henry Graham, 5 Great George Street, Westminster, S.W.

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1885. Harris, John Henry, Worthington Pumping Engine Co., 114 Queen Victoria Street, London, E.C. [*Tuncharp, London.*]

1873. Harris, Richard Henry, 63 Queen Victoria Street, London, E.C.

1877. Harris, William Wallington, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.; and 24 Alexandra Villas, Hornsey Park, London, N.

1885. Harrison, Frederick Henry, Lincoln Malleable Iron Works, Lincoln.

1885. Harrison, Joseph, Normal School of Science, South Kensington, London, S.W.

1858. Harrison, Thomas Elliot, Engineer-in-Chief, North Eastern Railway, Newcastle-on-Tyne.

1883. Hart, Frederick, Pottstown, Montgomery County, Pennsylvania, United States: (or care of A. Pye-Smith, Messrs. Samuel Osborn and Co., 16 Philpot Lane, London, E.C.)

1877. Hart, James, 138 Portland Street, Southport.

1882. Hart, Norman, care of Colonel Beaumont, 2 Victoria Mansions, Victoria Street, Westminster, S.W.

1872. Hartnell, Wilson, Benson's Buildings, Park Row, Leeds.

1882. Harvey, Charles Randolph, Messrs. G. and A. Harvey, Albion Machine Works, Govan, near Glasgow.

1883. Harvey, Robert, Messrs. North and Harvey, Liverpool Nitrate Works, Iquique, Chile.

1878. Harwood, Robert, Soho Iron Works, Bolton.

1882. Haskins, John Ferguson, 114A Queen Victoria Street, London, E.C.

1881. Haslam, Alfred Seale, Union Foundry, Derby. [*Zero, Derby.*]

1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.

1885. Hatton, Robert James, Henley's Telegraph Works, North Woolwich, London, E.

1857. Haughton, S. Wilfred (*Life Member*), Greenbank, Carlow, Ireland.

1878. Haughton, Thomas, 110 Cannon Street, London, E.C. [*Haughnot, London.*]

1885. Haughton, Thomas James, Mining Engineer, 69 Brecknock Road, London, N.

1861. Hawkins, William Bailey, 39 Lombard Street, London, E.C.

1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.

1856. Hawksley, Thomas, F.R.S., 30 Great George Street, Westminster, S.W.

1873. Hay, James A. C., Superintendent of Machinery to the War Department, Royal Arsenal, Woolwich.

1882. Hayes, Edward, Watling Works, Stony Stratford. [*Hayes, Stony Stratford.*]

1879. Hayes, John, 27 Leadenhall Street, London, E.C. [*Orbit, London.*]

1862. Haynes, Thomas John, Calpe Foundry and Forge, North Front, Gibraltar.

1880. Hayter, Harrison, 33 Great George Street, Westminster, S.W.

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1869. Head, Jeremiah, Messrs. Fox Head and Co., Newport Rolling Mills, Middlesbrough. [*Head, Foxhead, Middlesbrough.* 22.]

1873. Headly, Lawrance, Exchange Iron Foundry and Implement Works, Corn Exchange Street, Cambridge; and 1 Camden Place, Cambridge. [*Vanes, Cambridge.*]

1857. Healey, Edward Charles, 163 Strand, London, W.C.

1872. Heap, William, 9 Rumford Place, Liverpool. [*Metal, Liverpool.* 809.]

1864. Heathfield, Richard, Messrs. Morewood and Co., Lion Galvanising Works, Birmingham Heath, Birmingham.

1875. Heenan, Richard Hammersley, Messrs. Heenan and Froude, Newton Heath Iron Works, near Manchester. [*Spherical, Newton Heath.*]

1879. Henchman, Humphrey, care of John Henchman, Uplands, Wallington, Surrey.

1869. Henderson, David Marr, Engineer-in-Chief, Imperial Maritime Customs Service of China, Shanghai, China.

1883. Henderson, John Baillie, Engineer to the Queensland Government, Water Supply Department, Brisbane, Queensland.

1883. Henderson, William, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.

1878. Henesey, Richard, Messrs. Donald Henesey and Couper, Ripon Iron Works, Frere Road, Bombay; and 3 Beckett Terrace, Uxbridge.

1879. Henriques, Cecil Quixam, Parliament Mansions, Westminster, S.W.

1875. Hepburn, George, Redcross Chambers, Redcross Street, Liverpool. [*Hepburn, Liverpool.*]

1876. Heppell, Thomas, Mining Engineer, Ouston Collieries, Chester-le-Street.

1877. Hepworth, Thomas Howard, Curzon House, Curzon Street, Derby.

1884. Hernu, Arthur Henry, 35 Bedford Street, Strand, London, W.C.

1884. Hervey, Matthew Wilson, Assistant Engineer, West Middlesex Water Works, Hammersmith, London, W.

1879. Hesketh, Everard, Messrs. J. and E. Hall, Iron Works, Dartford. [*Hesketh, Dartford.*]

1865. Hetherington, John Muir, Vulcan Works, Pollard Street, Manchester.

1866. Hetherington, Thomas Ridley, Vulcan Works, Pollard Street, Manchester.

1872. Hewlett, Alfred, Haseley Manor, Warwick.

1872. Hewlett, William Henry, Wigan Coal and Iron Works, Kirkless Hall, Wigan.

1871. Hick, John, M.P., Mytton Hall, Whalley, near Blackburn.

1885. Hicken, Thomas, Dunchurch, Rugby.

1864. Hide, Thomas C., 4 Cullum Street, Fenchurch Street, London, E.C.

1879. Higson, Jacob, Mining Engineer, Crown Buildings, 18 Booth Street Manchester.

1871. Hill, Alfred C., Clay Lane Iron Works, South Bank, R.S.O., Yorkshire.

1885. Hill, Robert Anderson, Royal Mint, Little Tower Hill, London, E.

1882. Hiller, Henry, Chief Engineer, National Boiler Insurance Company, 22 St. Ann's Square, Manchester.

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1873. Hilton, Franklin, Chief Engineer, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough; and South Bank, R.S.O., Yorkshire.
1876. Hind, Thomas William, Messrs. Henry Hind and Son, Central Engineering Tool Works, Queen's Road, Nottingham [*Hind, Nottingham.*]; and 62 Blackfriars Road, London, S.E.
1885. Hindmarsh, Thomas, 303 King Street West, Hammersmith, London, W.
1870. Hodges, Petronius, 238 Barnsley Road, Sheffield.
1880. Hodgson, Charles, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W.
1882. Hodson, Richard, Thames Iron Works and Shipbuilding Co., Blackwall, London, E.
1884. Hogg, William Thomas, Ram Brewery, Wandsworth, London, S.W.
1852. Holcroft, James, Red Hill House, Stourbridge.
1866. Holcroft, Thomas, Bilston Foundry, Bilston.
1884. Holland, Calvert Bernard, General Manager, Ebbw Vale Steel Iron and Coal Works, Ebbw Vale, R.S.O., Monmouthshire.
1865. Holliday, John, Messrs. John Bethell and Co., Creosote Works, Westbromwich; and Oakfield Lodge, Booth Street, Handsworth, Birmingham.
1885. Hollis, Henry William, General Manager, Butterley Iron Works, near Alfreton.
1883. Holroyd, John, Tomlinson Street, Hulme, Manchester.
1863. Holt, Francis, Midland Railway, Locomotive Department, Derby.
1873. Holt, Henry Percy, The Cedars, Didsbury, Manchester.
1867. Holt, William Lyster, 17 Parliament Street, Westminster, S.W.
1867. Homer, Charles James, Mining Engineer, Ivy House, Stoke-upon-Trent.
1848. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, London, W.C.
1883. Hooton, William, Continental Lace-Machine Works, Great Eastern Street, Nottingham.
1866. Hopkins, John Satchell, Jesmond Grove, Highfield Road, Edgbaston, Birmingham.
1885. Hopkinson, Charles, Werneth Chambers, 29 Princess Street, Manchester.
1856. Hopkinson, John, Grove House, Oxford Road, Manchester.
1874. Hopkinson, John, Jun., D.Sc., F.R.S., Lighthouse Department, Messrs. Chance Brothers and Co., Spon Lane, near Birmingham; and 4 Westminster Chambers, Victoria Street, Westminster, S.W. [3092.]
1877. Hopkinson, Joseph, Messrs. Joseph Hopkinson and Co., Britannia Works, Huddersfield.
1867. Hopper, William, Machine Works, Moscow: (or care of Thomas Hopper, 18 Ann Street, Edinburgh.)
1880. Hornsby, James, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.

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1873. Horsley, Charles, 22 Wharf Road, City Road, London, N.

1868. Horsley, Thomas, King's Newton, near Derby.

1858. Horsley, William, Whitehill Point Iron Works, Percy Main, near Newcastle-on-Tyne.

1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury.

1871. Horton, George, Messrs. Horton and Son, Steam Boiler Works, 63 Park Street, Southwark, London, S.E.

1875. Hosgood, Thomas Hopkin, Richardson Street, Swansea.

1873. Hoskin, Richard, 1 East Parade, Sheffield.

1866. Houghton, John Campbell Arthur, Woodside Iron Works, near Dudley.

1864. Howard, Eliot, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1860. Howard, James, M.P., Messrs. J. and F. Howard, Britannia Iron Works, Bedford; and Clapham Park, Bedfordshire.

1882. Howard, John William, 78 Queen Victoria Street, London, E.C.

1867. Howard, Robert Luke, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1885. Howarth, William, Manager, Oldham Boiler Works, Oldham.

1861. Howell, Joseph Bennett, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield.

1877. Howell, Samuel Earnshaw, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield.

1882. Howl, Edmund, Messrs. Lee Howl Ward and Howl, Tipton.

1877. Howlett, Francis, Messrs. Henry Clayton Son and Howlett, Atlas Works, Woodfield Road, Harrow Road, London, W. [*Brickpress, London.*]

1884. Hoyle, Frank Edward, Locomotive Superintendent, Bahia and San Francisco Railway, Periperi, Bahia, Brazil: (or care of Leonard Micklem, Secretary, Bahia and San Francisco Railway, 38 New Broad Street, London, E.C.)

1882. Hudson, John George, Messrs. Mirrlees Watson and Co., 45 Scotland Street, Glasgow.

1884. Hudson, Robert, Gildersome Foundry, near Leeds [*Gildersome, Leeds.* 14.]; and Weetwood Mount, Headingley, near Leeds. [454.]

1881. Hughes, Edward William Mackenzie, Locomotive and Carriage Superintendent, Indus Valley State Railway, Sukkur, Sindh, India: (or care of Charles William Lennox, 13 Derby Crescent, Kelvinside, N., Glasgow.)

1867. Hughes, George Douglas, Queen's Foundry, London Road, Nottingham.

1871. Hughes, Joseph, Lowca Engineering Co., Lowca Engine Works, near Whitehaven; and Moresby, near Whitehaven.

1864. Hulse, William Wilson, Ordsal Tool Works, Regent Bridge, Salford, Manchester.

1880. Humphrys, James, 16 and 17 Leadenhall Buildings, London, E.C.; and Arundel House, Lancaster Road, South Norwood Park, London, S.E.

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1866. Humphrys, Robert Harry, Messrs. Humphrys Tennant and Co., Deptford Pier, London, S.E.

1882. Hunt, Reuben, Aire and Calder Chemical Works, Castleford, near Normanton.

1885. Hunt, Richard, Messrs. Thomas Hunt and Sons, 132 Bridge Road West, Battersea, London, S.W.

1856. Hunt, Thomas, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1874. Hunt, William, Alkali Works, Lea Brook, Wednesbury; Hampton House, Wednesbury; and Aire and Calder Chemical Works, Castleford, near Normanton.

1877. Hunter, Walter, Messrs. Hunter and English, High Street, Bow, London, E.

1865. Hyde, Major-General Henry, R.E. (*Life Member*), India Office, Westminster, S.W.

1885. Hyland, John Frank, Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.; and 91 High Street, Ashford, Kent.

1877. Imray, John, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C.

1882. Ingham, William, 22 St. Ann's Square, Manchester.

1872. Inman, Charles Arthur, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead; and 45 North Corridor, The Albany, Liverpool.

1883. Instone, Thomas, Assistant Manager and Engineer, Elliott's Metal Works, Selly Oak, near Birmingham; and Harborne, near Birmingham.

1872. Jack, Alexander, Messrs. James Jack and Co., Victoria Engine Works, Boundary Street West, Vauxhall Road, Liverpool.

1884. Jacks, Thomas William Moseley, Patent Shaft Works, Wednesbury; and 72 Stafford Street, Wednesbury.

1859. Jackson, Matthew Murray, Rocklands, Auckland Road, Upper Norwood, London, S.E.; and care of Messrs. Howard and Pitcairn, 155 Fenchurch Street, London, E.C.

1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester; and Blackbrooke, Pontrilas, R.S.O., Herefordshire.

1873. Jackson, Samuel, C.I.E., Locomotive and Carriage Superintendent, Great Indian Peninsula Railway, Bombay.

1872. Jackson, William Francis, Bowling Iron Works, near Bradford.

1873. Jacob, Edward Westley, Tees Side Iron and Engine Works, Middlesbrough; and 75 Grange Road West, Middlesbrough.

1876. Jacobs, Charles Mattathias, 126 Bute Docks, Cardiff. [*Engineer, Cardiff*.29.

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1878. Jakeman, Christopher John Wallace, Manager, Messrs. Merryweather and Sons, Tram Locomotive Works, Greenwich Road, London, S.E.

1877. James, Christopher, 4 Alexandra Road, Clifton, Bristol.

1877. James, John William Henry, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1879. Jameson, George, Glencormac, Bray, Ireland.

1881. Jameson, John, Messrs. Jameson and Schaeffer, Akenside Hill, Newcastle-on-Tyne.

1882. Jardine, John, Lace Machine Works, Raleigh Street, Nottingham. [*Jardine, Nottingham.*]

1876. Jebb, George Robert, Engineer to the Birmingham Canal Navigation, Birmingham; and The Laurels, Shrewsbury.

1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.

1880. Jefferies, John Robert, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich.

1881. Jefferiss, Thomas, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham.

1863. Jeffreys, Edward A., Monk Bridge Iron Works, Leeds; and Gipton Lodge, Leeds.

1877. Jeffreys, Edward Homer, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1875. Jenkin, H. C. Fleeming, F.R.S., Professor of Engineering, University of Edinburgh; 3 Great Stuart Street, Edinburgh.

1884. Jenkins, Alfred, Bridge Wharf Foundry, Abergavenny.

1878. Jensen, Peter, 77 Chancery Lane, London, W.C. [*Venture, London.*]

1854. Jobson, John, Derwent Foundry, Derby.

1863. Johnson, Bryan, Hydraulic Engineering Works, Chester; and 34 King Street, Chester.

1882. Johnson, Charles Malcolm, Chief Engineer, R.N., H. M. Ironclad "Swiftsure," Esquimalt, Vancouver Island; and 11 Napier Street, Stoke, Devonport.

1885. Johnson, John Clarke, Messrs. James Russell and Sons, Crown Tube Works, Wednesbury.

1882. Johnson, Samuel, Manager, Globe Cotton and Woollen Machine Works, Rochdale.

1861. Johnson, Samuel Waite, Locomotive Superintendent, Midland Railway, Derby.

1872. Joicey, Jacob Gowland, Messrs. J. and G. Joicey and Co., Forth Banks West Factory, Newcastle-on-Tyne. [*Engines, Newcastle-on-Tyne.*]

1882. Jolin, Philip, 35 Narrow Wine Street, Bristol; and 2 Elmdale Road, Redland, Bristol.

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1871. Jones, Charles Henry, Assistant Locomotive Superintendent, Midland Railway, Derby.

1873. Jones, Edward, Messrs. Greenwood and Batley, Albion Works, Leeds; and 13 Blenheim Square, Leeds.

1873. Jones, Edward Trygarn, Consulting Engineer to the Commercial Steam Ship Co., 32 Great St. Helen's, London. E.C.

1884. Jones, Felix, Messrs. Jones and Foster, 39 Bloomsbury Street. Birmingham.

1878. Jones, Frederick Robert, Superintending Engineer, Sirmoor State, Nahan, near Umballa, Punjaub, India: (or care of Messrs. Richard W. Jones and Co., Newport, Monmouthshire.)

1867. Jones, George Edward, Sakkur, near Karachi, Punjaub, India: (or care of Mrs. Edward Jones, 9 Sydenham Villas, Cheltenham.)

1878. Jones, Harry Edward, Engineer, Commercial Gas Works, Stepney, London, E.

1881. Jones, Herbert Edward, Locomotive Department, Midland Railway, Manchester.

1882. Jones, Samuel Gilbert, Bombay Burmah Trading Corporation, Rangoon, British Burmah: (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1872. Jones, William Richard Sumption, Rajputana State Railway, Ajmeer, India: (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)

1883. Jordan, Edward, Manager, Cardiff Junction Dry Dock and Engineering Works, Cardiff.

1884. Josse, Hippolyte, 15 Rue Drouot, Paris.

1880. Joy, David, 8 Victoria Chambers, Victoria Street, Westminster, S.W.; and 32 Anerley Park, Anerley, London, S.E.

1878. Jüngermann, Carl, Märkisch Schlesische Maschinenbau und Hütten Actien Gesellschaft, 3 Chaussée Strasse, Berlin.

1884. Justice, Howard Rudulph, 55 and 56 Chancery Lane, London, W.C. [*Syng, London.* 2504.]

1882. Keeling, Herbert Howard, Merlewood, Eltham.

1869. Keen, Arthur, Patent Nut and Bolt Works, Smethwick, near Birmingham.

1867. Kellett, John, Clayton Street, Wigan.

1873. Kelson, Frederick Colthurst, Angra Bank, Waterloo Park, Waterloo, near Liverpool.

1881. Kendal, Ramsey, Locomotive Department, North Eastern Railway, Gateshead.

1885. Kendall, George, Lloyd's Register of Shipping, Dock Street, Newport, Monmouthshire.

1863. Kennan, James, Messrs. Kennan and Sons, Engineering Works, Fishamble Street, Dublin.

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1879. Kennedy, Alexander Blackie William, Professor of Engineering, University College, Gower Street, London, W.C.

1847. Kennedy, James, Gilmerton, Cressington Park, Aigburth, Liverpool.

1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway, 45 Finsbury Circus, London, E.C.; and 29 Lupus Street, St. George's Square, London, S.W.

1868. Kennedy, Thomas Stuart, Windham Club, 13 St. James' Square, London, S.W.

1875. Kenrick, George Hamilton, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich; and Whetstone, Somerset Road, Edgbaston, Birmingham.

1866. Kershaw, John, 9 Duke Street, Portland Place, London, W.

1884. Kershaw, Thomas Edward, Chilvers Coton Foundry, Nuneaton.

1880. Kessler, Emil, Maschinenfabrik, Esslingen, Wurtemberg, Germany.

1885. Keydell, Amandus Edmund, Lloyd's Register of Shipping, Cardiff.

1885. Keymer, Henry John Cubitt, Fisheries Iron Works, Gorleston, Great Yarmouth.

1885. Kidd, Hector, Colonial Sugar Refining Co., Sydney, New South Wales.

1872. King, William, Engineer, Liverpool United Gas Works, Duke Street, Liverpool.

1872. Kirk, Alexander Carnegie, Messrs. Robert Napier and Sons, Lancefield House, Glasgow; and Govan Park, Govan, Glasgow.

1877. Kirk, Henry, Messrs. Kirk Brothers and Co., New Yard Iron Works, Workington.

1884. Kirkaldy, John, 40 West India Dock Road, London, E. [*Compactum, London.*]

1875. Kirkwood, James, Chief Inspector of Machinery for Pei Yang Squadron; care of Imperial Maritime Customs, Chefoo, China.

1864. Kirtley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W. [3005.]

1859. Kitson, James, Monk Bridge Iron Works, Leeds.

1863. Kitson, John Hawthorn, Airedale Foundry, Leeds. [*Airedale, Leeds.*]

1874. Klein, Thorvald, Suffolk House, Laurence Pountney Hill, London, E.C.

1877. Kortright, Lawrence Moore, Superintendent of Public Works, St. Kitts, West Indies: (or care of G. D. Kortright, Plas Teg, near Mold, Flintshire.)

1881. Laing, Arthur, Deptford Shipbuilding Yard, Sunderland.

1872. Laird, Henry Hyndman, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.

1872. Laird, William, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.

1883. Lake, William Robert, 8 Southampton Buildings, London, W.C.

1873. Lamb, William James, Newtown and Meadows Collieries, near Wigan.

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1878. Lambourn, Thomas William, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich.

1881. Langdon, William, Locomotive Superintendent and Chief Mechanical Engineer, Rio Tinto Railway and Mines, Huelva, Spain: (or care of William G. Parsons, 11 Queen Victoria Street, London, E.C.)

1881. Lange, Frederick Montague Townshend, Messrs. Lange's Wool-Combing Works, Saint Acheul-les-Amiens, Somme, France.

1877. Lange, Hermann Ludwig, Manager, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1879. Langley, Alfred Andrew, Engineer-in-Chief, Midland Railway, Derby.

1879. Lapage, Richard Herbert, Bank Chambers, 109 New Oxford Street, London, E.C.

1879. Larsen, Jorgen Daniel, 24 Belvedere Road, Upper Norwood, London, S.E.

1881. Lavalley, Alexander, 48 Rue de Provence, Paris.

1867. Lawrence, Henry, The Grange Iron Works, Durham.

1874. Laws, William George, Borough Engineer and Town Surveyor, Town Hall, Newcastle-on-Tyne; and 5 Winchester Terrace, Newcastle-on-Tyne. [*Engineer, Newcastle-on-Tyne.*]

1882. Lawson, Frederick William, Messrs. Samuel Lawson and Sons, Hope Foundry, Leeds.

1870. Layborn, Daniel, Messrs. Caine and Layborn, Dutton Street, Liverpool.

1856. Laybourne, Richard, Isca Foundry, Newport, Monmouthshire.

1883. Laycock, William S., Messrs. Samuel Laycock and Sons, Horse-hair Cloth Works, Sheffield; and Ranmoor, Sheffield.

1860. Lea, Henry, 38 Bennett's Hill, Birmingham. [*Engineer, Birmingham.* 113.]

1884. Leake, Arthur Hill, Sugar Engineer, Post Office, Brisbane, Queensland: (or care of Henry I. Wenham, 43 Finsbury Circus, London, E.C.)

1883. Leavitt, Erasmus Darwin, Jun., 604 Main Street, Cambridgeport, Massachusetts, United States.

1865. Ledger, Joseph, Keswick.

1862. Lee, J. C. Frank, 9 Park Crescent, Portland Place, London, W.

1871. Lee, William, Messrs. Lee Clerk and Robinson, Gospel Oak Iron Works, Tipton; and 110 Cannon Street, London, E.C.

1863. Lees, Samuel, Messrs. H. Lees and Sons, Park Bridge Iron Works, Ashton-under-Lyne.

1883. Lennox, John, 2 Victoria Mansions, Victoria Street, Westminster, S.W.

1882. Léon, Auguste, Locomotive Engineer, Chemins de fer de Paris à Lyon et à la Méditerranée, 220 Boulevard Voltaire, Paris.

1858. Leslie, Andrew, Messrs. R. and W. Hawthorn Leslie and Co., Iron Shipbuilding Yard, Hebburn, Newcastle-on-Tyne.

1883. Leslie, Joseph, Marine Engineer, Messrs. Apcar and Co., Raddah Bazar, Calcutta.

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1878. Lewis, Gilbert, Manager, New Bridge Foundry, Adelphi Street, Salford, Manchester.

1884. Lewis, Henry Watkin, Bute Shipbuilding and Engineering Works, Cardiff.

1872. Lewis, Richard Amelius, Messrs. John Spencer and Sons, Tyne Hæmatite Iron Works, Scotswood-on-Tyne.

1884. Lewis, Sir William Thomas, Bute Mineral Estate Office, Aberdare; and Mardy, Aberdare.

1880. Lightfoot, Thomas Bell, Cornwall Buildings, 35 Queen Victoria Street, London, E.C.

1856. Linn, Alexander Grainger, 121 Upper Parliament Street, Liverpool.

1876. Lishman, Thomas, Mining Engineer, Hetton Colliery, near Fence Houses.

1881. List, John, Superintendent Engineer, Messrs. Donald Currie and Co., Orchard Works, Blackwall, London, E.

1885. Lister, Frank, Messrs. Wilkinson and Lister, Bradford Road Works, Keighley.

1866. Little, George, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1867. Livesey, James, 2 Victoria Mansions, Victoria Street, Westminster, S.W.

1867. Lloyd, Charles, 69 Millbank Street, Westminster, S.W.

1871. Lloyd, Francis Henry, James Bridge Steel Works, near Wednesbury [*Steel, Wednesbury.*]; and Wood Green, Wednesbury.

1854. Lloyd, George Braithwaite (*Life Member*), Edgbaston Grove, Birmingham.

1882. Lloyd, Robert Samuel, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1864. Lloyd, Sampson Zachary, Areley Hall, Stourport.

1852. Lloyd, Samuel, The Farm, Sparkbrook, Birmingham.

1879. Lockhart, William Stronach, Fenchurch House, 7 Fenchurch Street, London, E.C.

1881. Lockyer, Norman Joseph, St. Mildred's Road, Westgate-on-Sea.

1884. Logan, Andrew Linton, Lochalsh, Scotland.

1883. Logan, Robert Patrick Tredennick, Engineer's Office, Great Northern Railway of Ireland, Dundalk.

1874. Logan, William, Mining Engineer, Langley Park Colliery, Durham.

1884. Longbottom, Luke, Locomotive Carriage and Wagon Superintendent, North Staffordshire Railway, Stoke-on-Trent.

1885. Longden, John Needham, Mining Engineer, Messrs. W. Pritchard-Morgan and Co., 1 Queen Victoria Street, London, E.C.

1880. Longridge, Michael, Chief Engineer, Engine and Boiler Insurance Co., 12 King Street, Manchester.

1856. Longridge, Robert Bewick, Managing Director, Engine and Boiler Insurance Co., 12 King Street, Manchester; and Yew Tree House, Tabley, near Knutsford.

1875. Longridge, Robert Charles, Kilrie, Knutsford.

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1880. Longworth, Daniel, Carnac Iron Works, Bombay.
1882. Lord, Walter, Messrs. Lord Brothers, Canal Street Works, Todmorden.
1861. Low, George, Bishop's Hill Cottage, Ipswich.
1885. Low, Robert, Laboratory Department, Royal Arsenal, Woolwich.
1884. Lowcock, Arthur, Colcham Foundry, Shrewsbury.
1884. Lowdon, John, Manager, Tyneside Engine Works, Cardiff.
1873. Lowe, John Edgar, Messrs. Bolling and Lowe, 2 Laurence Pountney Hill, London, E.C. [*Bird, London.* 1530.]
1883. Lowe, Sutton Harvey, Eastgate House, Lincoln.
1873. Lucas, Arthur, 15 George Street, Hanover Square, London, W.
1877. Lupton, Arnold, 4 Albion Place, Leeds.
1878. Lynde, James Henry, 32 St. Ann's Street, Manchester.

1883. Macbeth, Norman, Messrs. John and Edward Wood, Victoria Foundry, Bolton.
1884. MacCarthy, Samuel, Messrs. Hathorn Davey and Co., Sun Foundry, Leeds.
1877. MacColl, Hector, Messrs. James Jack and Co., Victoria Engine Works, Boundary Street West, Vauxhall Road, Liverpool.
1879. Macdonald, Augustus Van Zundt, District Manager, New Zealand Railways, Napier, New Zealand.
1864. Macfarlane, Walter, Saracen Foundry, Possilpark, Glasgow.
1885. Mackenzie, John William, Messrs. Wheatley and Mackenzie, 156 Strand, London, W.C.
1884. Mackintosh, Archibald Robert, Messrs. Lindsay Gracie and Co., Quay Side, Newcastle-on-Tyne.
1875. Maclagan, Robert, Chief Engineer, Imperial Mint, Osaka, Japan: (or care of Dr. Maclagan, 9 Cadogan Place, Belgrave Square, London, S.W.)
1877. MacLellan, John A., Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow.
1864. Macnab, Archibald Francis, Inspecting and Examining Engineer, Government Marine Office, Tokio, Japan.
1865. Macnee, Daniel, 2 Westminster Chambers, Victoria Street, Westminster, S.W. [*Macnee, London.*]; and Rotherham.
1884. Macpherson, Alexander Sinclair, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.
1879. Maginnis, James Porter, 9 Carteret Street, Queen Anne's Gate, Westminster, S.W.
1873. Mair, John George, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.
1884. Mais, Henry Coathupe, Engineer-in-Chief to the Government of South Australia, Adelaide, South Australia: (or care of Joseph Meilbek, 7 Westminster Chambers, Victoria Street, Westminster, S.W.)

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1879. Malcolm, Bowman, Locomotive Superintendent, Belfast and Northern Counties Railway, Belfast.

1881. Mallory, George Benjamin, 55 Broadway, New York.

1882. Mañé, Marcos, Ingeniero Mecanico, Ferro Carril Oeste, Buenos Aires.

1876. Manlove, William Melland, Messrs. S. Manlove and Sons, Holy Moor Sewing-Cotton Spinning Mills, near Chesterfield.

1862. Mansell, Richard Christopher, Mechanical Engineer, South Eastern Railway; 24 Caversham Road, Kentish Town, London, N.W.

1875. Mansergh, James, 3 Westminster Chambers, Victoria Street, Westminster, S.W.

1862. Mappin, Frederick Thorpe, M.P., Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield; and Thornbury, Sheffield.

1882. Mappin, Walter Sandell, 13 Cornhill, London, E.C.

1857. March, George, Messrs. Maclea and March, Union Foundry, Dewsbury Road, Leeds. [*Maclea, Leeds.*]

1878. Marié, Georges, Engineer, Chemins de fer de Paris à Lyon et à la Méditerranée, Bureaux du Matériel, Boulevart Mazas, Paris.

1856. Markham, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield; and Tapton House, Chesterfield.

1884. Marquand, Augustus John, 109 Rothesay Terrace, Bute Docks, Cardiff.

1871. Marsh, Henry William, Winterbourne, near Bristol.

1875. Marshall, Alfred (*Life Member*), Perseverance Iron Works, Heneage Street, Whitechapel, London, E.; and Laurel Bank, Prospect Hill, Walthamstow, Essex.

1865. Marshall, Francis Carr, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1885. Marshall, Henry Dickenson, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 6648.]

1871. Marshall, James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 6648.]

1885. Marshall, Jenner Guest, Westcott Barton Manor, Oxfordshire.

1877. Marshall, William Bayley, 15 Augustus Road, Birmingham. [*Augustus, Birmingham.*]

1847. Marshall, William Prime, 15 Augustus Road, Birmingham. [*Augustus, Birmingham.*]

1859. Marten, Edward Bindon, Chief Engineer, Midland Steam Boiler Inspection and Assurance Company, 56 Hagley Street, Stourbridge [*Marten, Stourbridge.*]; Podmore, Stourbridge; and 4 Storey's Gate, Westminster, S.W.

1853. Marten, Henry John, The Birches, Codsall, near Wolverhampton; and 4 Storey's Gate, Westminster, S.W.

1881. Martin, Edward Pritchard, Dowlais Iron Works, Dowlais.

1878. Martin, Henry, Hanwell, Middlesex, W.

1880. Martin, Robert Frewen, Mount Sorrel Granite Co., Loughborough.

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1882. Masefield, Robert, Manor Iron Works, Manor Street, Chelsea, London, S.W.
1884. Massey, George, Foy's Chambers, Bond Street, Sydney, New South Wales.
1876. Mather, John, London and South Western Railway, Locomotive Department, Nine Elms, London, S.W.
1867. Mather, William, M.P., Messrs. Mather and Platt, Salford Iron Works, Manchester.
1883. Mather, William Penn, Messrs. Mather and Platt, Salford Iron Works, Manchester.
1882. Matheson, Henry Cripps, care of Messrs. Russell and Co., Hong Kong, China: (or care of Messrs. Matheson and Grant, 32 Walbrook, London, E.C.)
1875. Matthews, James, 22 Ashfield Terrace East, Newcastle-on-Tyne.
1875. Mattos, Antonio Gomes de, Messrs. Maylor and Co., Engineering Works, 136 Rua da Sande, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)
1853. Maudslay, Henry (*Life Member*), Westminster Palace Hotel, Victoria Street, Westminster, S.W.: (or care of John Barnard, 47 Lincoln's Inn Fields, London, W.C.)
1869. Maughan, Thomas, Engineer, Cramlington Colliery, Cramlington, Northumberland.
1873. Maw, William Henry, 35 Bedford Street, Strand, London, W.C.
1884. Maxim, Hiram Stevens, 57D Hatton Garden, London, E.C. [*Maxim, London.* 6507.]
1865. Maylor, John, Churton Lodge, Churton, near Chester.
1859. Maylor, William, Calicut, Malabar Coast, India: (or care of Messrs. Leslie and Anderson, 2 Lime Street Square, London, E.C.)
1874. McClean, Frank, 23 Great George Street, Westminster, S.W.
1872. McConnochie, John, Engineer to the Bute Harbour Trust, 16 Bute Crescent, Bute Docks, Cardiff.
1878. McDonald, John Alexander, Assistant Engineer for Roads and Bridges, Public Works Office, Sydney, New South Wales: (or care of James E. McDonald, 4 Chapel Street, Cripplegate, London, E.C.)
1865. McDonnell, Alexander, Saltwell Hall, Gateshead.
1881. McGregor, Josiah, Crown Buildings, 78 Queen Victoria Street, London, E.C. [*Sahib, London.*]
1868. McKay, Benjamin, Ellerslie, Mackay, Queensland: (or care of Henry C. Halliday, 4 Chestnut Grove, Springfield, Sale, Manchester.)
1881. McKay, John, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.
1880. McLachlan, John, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]
1882. McLaren, Raynes Lauder, Bourse Buildings, 20 Bucklersbury, London, E.C.; and 14 Royal Parade, Blackheath, London, S.E. [*Pellmack, London.*]

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1879. McLean, William Leckie Ewing, Lancefield Forge Co., Glasgow.
1885. McNeil, John, Messrs. Aitken McNeil and Co., Helen Street, Govan, Glasgow. [*Colonial, Govan.*]
1884. McOnie, William, Jun., Messrs. W. and A. McOnie, Scotland Street Engine Works, Glasgow.
1882. Meats, John Tempest, Mason Machine Works, Taunton, Massachusetts, United States.
1863. Meek, Sturges, Consulting Engineer, Lancashire and Yorkshire Railway, Manchester; and Dunstall Lodge, 18 Holland Villas Road, London, W.
1881. Meik, Charles Scott, 6 York Place, Edinburgh.
1858. Meik, Thomas, 6 York Place, Edinburgh.
1883. Melrose, James, Chief Engineer, H.M. Dockyard, Gibraltar.
1878. Menier, Henri, 56 Rue de Châteaudun, Paris.
1876. Menzies, William, Messrs. Menzies and Blagburn, 9 Dean Street, Newcastle-on-Tyne.
1875. Merryweather, James Compton, Messrs. Merryweather and Sons, Fire-Engine Works, Greenwich Road, London, S.E.; and 63 Long Acre, London, W.C.
1881. Meysey-Thompson, Arthur Herbert, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds.
1877. Michele, Vitale Domenico de, 14 Delahay Street, Westminster, S.W.; and Higham Hall, Rochester.
1884. Middleton, Reginald Empson, Forth Bridge, South Queensferry, Scotland.
1862. Miers, Francis C., Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.; and Eden Cottage, West Wickham Road, Beckenham.
1864. Miers, John William, 74 Addison Road, Kensington, London, W.
1874. Milburn, John, Hawkshead Foundry, Quay Side, Workington.
1885. Miller, Harry William, Engineer, Pioneer Powder Factory, Bariaanspoort, Pretoria, South Africa.
1885. Millis, Charles Thomas, Technical College, Finsbury, London, E.C.
1856. Mitchell, Charles, Sir W. G. Armstrong Mitchell and Co., Low Walker, Newcastle-on-Tyne; and Jesmond Towers, Newcastle-on-Tyne.
1870. Moberly, Charles Henry, Messrs. Easton and Anderson, Erith Iron Works, Erith, S. O., Kent.
1879. Moffat, Thomas, Mining Engineer, Montreal Iron Ore Mines, Whitehaven.
1885. Moir, James, Mechanical Engineer, Coorla, Bombay.
1879. Molesworth, Guilford Lindsay, Consulting Engineer to the Government of India for State Railways, Supreme Government, India.
1882. Molesworth, James Murray, Cape Copper Co., Ookiep, Namaqualand, Cape Colony; and Spotland Vicarage, Rochdale: (or care of Messrs. Price and Belsham, 52 Queen Victoria Street, London, E.C.)

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1881. Molinos, Léon, 48 Rue de Provence, Paris.
1885. Monk, Edwin, 21 Lacey Terrace, Gravesend.
1884. Monroe, Robert, Manager, Penarth Slipway and Engineering Works, Penarth Dock, Penarth.
1872. Moon, Richard, Jun., Penyvoel, Llanymynech, Montgomeryshire.
1884. Moore, Benjamin Theophilus, Cavendish House, Teddington, Middlesex.
1876. Moore, Joseph, Risdon Iron and Locomotive Works, San Francisco, California; 6 Durham Road, East End, Finchley, London, N.: (or care of Ralph Moore, Government Inspector of Mines, Rutherglen, Glasgow.)
1882. Moore, Richard St. George, Messrs. Clarke and Moore, 7 Westminster Chambers, Victoria Street, Westminster, S.W.
1872. Moorsom, Warren Maude, Linden Lodge, Clevedon.
1880. Moreland, Richard, Jun., Messrs. Richard Moreland and Son, 3 Old Street, St. Luke's, London, E.C.
1885. Morgan, Thomas Rees, Morgan Engineering Works, Alliance, Ohio, United States.
1867. Morgans, Thomas, The Guildhall, Bristol.
1874. Morris, Edmund Legh, New River Water Works, Finsbury Park, London, N.
1885. Morse, Harold, St. Mary's Vicarage, Nottingham.
1858. Mountain, Charles George, Rose Hill House, Coalbrookdale, Shropshire.
1884. Mower, George A., Crosby Steam Gage and Valve Co., 21 Cross Street, Finsbury, London, E.C.
1885. Mudd, Thomas, Manager, Messrs. William Gray and Co., Central Marine Engineering Works, West Hartlepool.
1873. Muir, Alfred, Messrs. William Muir and Co., Britannia Works, Sherborne Street, Strangeways, Manchester.
1873. Muir, Edwin, 26 King Street, Manchester.
1863. Muir, William, 2 Walbrook, London, E.C.; and 143 Brockley Road, New Cross, London, S.E.
1876. Muirhead, Richard, Messrs. Drake and Muirhead, Maidstone.
1865. Murdock, William Mallabey, Gilwern, near Abergavenny.
1881. Musgrave, James, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton.
1863. Musgrave, John, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton.
1882. Musgrave, Walter Martin, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton.

1870. Napier, James Murdoch, Messrs. David Napier and Son, Vine Street, York Road, Lambeth, London, S.E.
1861. Naylor, John William, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

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1883. Neate, Percy John, Messrs. Taylor and Neate, Medway Works, Rochester.
1863. Neilson, Walter Montgomerie, Hyde Park Locomotive Works, Glasgow; and Queen's Hill, Ringford, Kirkcudbrightshire.
1884. Nelson, John, 39 Bootham, York.
1881. Nesfield, Arthur, 7 Rumford Street, Liverpool.
1882. Nettlefold, Hugh, Screw Works, Broad Street, Birmingham.
1879. Neville, Robert, Butleigh Court, Glastonbury.
1879. Newall, Robert Stirling, F.R.S., Wire Rope Works, Gateshead; and Ferndene, Gateshead.
1866. Newdigate, Albert Lewis (*Life Member*), Engineer's Office, Dover Harbour, Dover.
1885. Newlove, Robert Robson, Crown Iron Works, Crocus Street, Nottingham. [*Newlove, Nottingham.*]
1881. Newman, Frederick, 5 Copthall Buildings, London, E.C.
1881. Nichol, Bryce Gray, Messrs. Donkin and Nichol, St. Andrew's Iron Works, Newcastle-on-Tyne.
1882. Nicholl, Edward McKillop, Bengal Public Works Department, Amritsar, Punjaub, India: (or care of Messrs. Henry S. King and Co., 65 Cornhill, London, E.C.)
1884. Nicholls, James Mayne, Locomotive Superintendent, Nitrate Railways, Iquique, Chile.
1884. Nicholson, Henry, 21 Flaxman Street, Liverpool.
1884. Nicholson, Thomas Head, Bedouin Steam Navigation Co., Liverpool; and 32 Rye Hill, Newcastle-on-Tyne.
1884. Nicholson, Walter Elliott, Oakfield, Ryton-on-Tyne, R. S. O., County Durham.
1877. Nicolson, Donald, 42 Highbury Hill, London, N.
1884. Noakes, Walter Maplesden, 43 York Street, Wynyard Square, Sydney, New South Wales.
1882. Nordenfelt, Thorsten, 53 Parliament Street, Westminster, S.W.
1866. Norfolk, Richard, Beverley.
1868. Norris, William Gregory, Coalbrookdale Iron Works, Coalbrookdale, Shropshire.
1869. North, Frederic William, Mining Engineer, Rowley Hall, near Dudley.
1883. North, Gamble, Messrs. North and Jewel, Peruano Nitrate of Soda and Iodine Works, Iquique, Chile: (or care of John T. North, Avery House, Avery Hill, Eltham.)
1882. North, John Thomas, Messrs. North Humphrey and Dickenson, Engineering Works, Iquique, Chile; and Avery House, Avery Hill, Eltham.
1878. Northcott, William Henry, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E.; and 7 St. Mary's Road, Peckham, London, S.E. [*Oxygen, London.* 8007.]
1882. Nunneley, Thomas, 9 Beech Grove Terrace, Leeds.

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1885. Oakes, Sir Reginald Louis, Bart., York Engineering Works, Leeman Road, York.

1868. O'Connor, Charles, Mersey Forge, Liverpool.

1875. Okes, John Charles Raymond, 39 Queen Victoria Street, London, E.C. [*Oaktree, London.* 1601.]

1866. Oliver, William, Victoria and Broad Oaks Iron Works, Chesterfield.

1882. Olrick, Harry, 27 Leadenhall Street, London, E.C.

1882. Orange, James, Surveyor General's Department, Hong Kong, China: (or care of Mrs. Mary Orange, 2 West End Terrace, Jersey.)

1885. Ormerod, Richard Oliver, 35 Philbeach Gardens, South Kensington, London, S.W.

1870. Osborn, Samuel, Clyde Steel and Iron Works, Sheffield.

1867. Oughterson, George Blake, care of Peter Brotherhood, Belvedere Road, Lambeth, London, S.E.

1868. Paget, Arthur, Machine Works, Loughborough.

1881. Palmer, Cecil Brooke, Minnie Moor Mining Co., Bellevue, Idaho, United States.

1877. Panton, William Henry, General Manager, Stockton Forge, Stockton-on-Tees.

1877. Park, John Carter, Locomotive Engineer, North London Railway, Bow, London, E.

1871. Parke, Frederick, Withnell Fire Clay Works, near Chorley.

1872. Parker, Thomas, Carriage Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.

1879. Parker, William, Chief Engineer Surveyor, Lloyd's Register, 2 White Lion Court, Cornhill, London, E.C.

1871. Parkes, Pershouse, 25 Exchange Buildings, Birmingham.

1884. Parlane, William, Hong Kong Ice Works, Eastpoint, Hong Kong, China.

1881. Parry, Henry, 2 Side, Newcastle-on-Tyne.

1880. Parsons, The Hon. Charles Algernon, Lauder Grange, Corbridge-on-Tyne.

1878. Parsons, The Hon. Richard Clere, Messrs. Kitson and Co., Airedale Foundry, Leeds.

1880. Paterson, Walter Saunders, Bombay Burmah Trading Corporation, Rangoon, British Burmah, India: (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1877. Paton, John McClure Caldwell, Messrs. Manlove Alliott Fryer and Co., Bloomsgrove Works, Ilkeston Road, Nottingham.

1881. Patterson, Anthony, Dowlais Iron Works, Dowlais.

1881. Pattinson, John, Locomotive Superintendent, Riazan and Kosloff Railway, Kosloff, Russia; 15 Princes Street, Yeovil: (or care of Nathaniel Grew, Dashwood House, 9 New Broad Street, London, E.C.)

1883. Pattison, Giovanni, Messrs. C. and T. T. Pattison, Engineering Works, Naples. [*Pattison, Naples.*]

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1884. Paul, Andrew Louis, Engineer, Oriental Telephone Co., India; (care of Messrs. Benn Ashley and Co., Bombay, India); and 38 Ashburn Place, London, S.W.

1872. Paxman, James Noah, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester. [*Paxman, Colchester.*]

1880. Peache, James Courthope, Messrs. Willans and Robinson, Ferry Works, Thames Ditton.

1869. Peacock, Ralph, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1869. Peacock, Ralph, Aire and Calder Foundry, Goole.

1847. Peacock, Richard, M.P., Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester; and Gorton Hall, Gorton, near Manchester.

1879. Pearce, George Cope, 2 St. Helen's Crescent, Swansea.

1873. Pearce, Richard, Deputy Carriage and Wagon Superintendent, East Indian Railway, Howrah, Bengal, India: (or care of W. J. Titley, 57 Lincoln's Inn Fields, London, W.C.)

1867. Pearce, Robert Webb, Carriage Superintendent, East Indian Railway, Howrah, Bengal, India; and 47 Gunterstone Road, West Kensington, London, W.

1884. Pearson, Frank Henry, Earle's Shipbuilding and Engineering Works, Hull.

1885. Pearson, Henry William, Engineer, Bristol Water Works, Small Street, Bristol.

1870. Pearson, Thomas Henry, Moss Side Iron Works, Ince, near Wigan.

1884. Penn, George Williams, Lloyd's Bute Proving House, Cardiff.

1873. Penn, John, Messrs. John Penn and Sons, Marine Engineers, Greenwich, S.E.

1873. Penn, William, Messrs. John Penn and Sons, Marine Engineers, Greenwich, S.E.

1874. Pepper, Joseph Ellershaw, Clarence Iron Works, Leeds.

1874. Percy, Cornelius McLeod, King Street, Wigan.

1861. Perkins, Loftus, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.

1879. Perkins, Stanhope, Assistant Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, Manchester.

1882. Perry, Alfred, Lighthouse Department, Messrs. Chance Brothers and Co., Spon Lane, near Birmingham.

1863. Perry, Thomas J., Highfields Engine Works, Bilston.

1865. Perry, William, Claremont Place, Wednesbury.

1882. Petherick, Vernon, Post Office, Brisbane, Queensland: (or care of Messrs. Manlove Alliott Fryer and Co., Ilkeston Road, Nottingham.)

1881. Philipson, John, Messrs. Atkinson and Philipson, Carriage Manufactory, 15 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]

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1885. Phillips, Charles David, Emlyn Engineering Works, Newport, Monmouthshire. [*Machinery, Newport, Mon.*]

1885. Phillips, Henry Parnham, Assistant Locomotive Superintendent, Burma State Railway, Insein, British Burma.

1878. Phillips, John, Manager, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.; and 84 Blackfriars Road, London, S.E.

1885. Phillips, Lionel, Mining Engineer, Bultfontein Diamond Mine, South Africa.

1879. Phillips, Robert Edward, Royal Courts Chambers, 70 and 72 Chancery Lane, London, W.C.; and Rochelle, Selhurst Road, South Norwood, London, S.E. [*Phicycle, London.*]

1882. Phipps, Christopher Edward, Deputy Locomotive Superintendent, Madras Railway, Perambore Works, Madras.

1876. Piercy, Henry James Taylor, Messrs. Piercy and Co., Broad Street Engine Works, Birmingham. [381.]

1877. Pigot, Thomas Francis, Professor of Engineering, Royal College of Science for Ireland, Dublin.

1883. Pillow, Edward, London and North Western Railway, Locomotive Department, Crewe.

1876. Pinel, Charles Louis, Messrs. Lethuillier and Pinel, 26 Rue Meridienne, Rouen, France.

1882. Pirrie, John Sinclair, Messrs. Timmins and Pirrie, 37 Walbrook, London, E.C. [*Byculla, London.*]

1883. Pitt, Walter, Messrs. Stothert and Pitt, Newark Foundry, Bath.

1871. Platt, James, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester.

1883. Platt, James Edward, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1867. Platt, Samuel Radcliffe, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1878. Platts, John Joseph, Resident Engineer, Odessa Water Works, Odessa, Russia.

1869. Player, John, Clydach Foundry, near Swansea.

1884. Poillon, Louis Marie Joseph, 74 Boulevard Mont-Parnasse, Paris.

1876. Pollock, Julius Frederick Moore, Messrs. Pollock and Pollock, Longclose Works, Newtown, Leeds.

1876. Pooley, Henry, Messrs. Henry Pooley and Son, Albion Foundry, Liverpool.

1869. Potter, William Aubone, Mining Engineer, Cramlington House, Cramlington, Northumberland.

1864. Potts, Benjamin Langford Foster, 55 Chancery Lane, London, W.C.; and 5 Camden Row, Camberwell, London, S.E.

1851. Potts, John Thorpe, Messrs. Richmond and Potts, 119 South Fourth Street, Philadelphia, Pennsylvania, United States.

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1878. Powell, Henry Coke, care of Thomas Powell, 23 Rue St. Julien, Rouen, France: (or care of C. M. Roffe, 1 Bedford Row, London, W.C.)
1870. Powell, Thomas (Son), Messrs. Thomas and T. Powell, 23 Rue St. Julien, Rouen, France.
1874. Powell, Thomas (Nephew), Brynhyfryd, Neath.
1867. Pratchitt, John, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.
1865. Pratchitt, William, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.
1885. Pratten, William John, Messrs. Harland and Wolff, Belfast.
1882. Presser, Ernest Charles Antoine, 4 Salesas, Madrid.
1884. Prest, Stanley Faber, Messrs. Westray Copeland and Co., Barrow-in-Furness.
1856. Preston, Francis, Netherfield House, Kirkburton, near Huddersfield. [*Preston, Kirkburton.*]
1877. Price, Henry Sherley, Messrs. Wheatley Kirk, Price, and Goulty, 52 Queen Victoria Street, London, E.C. [*Indices, London.* 1533.]
1866. Price, John, General Manager, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow; and Rose Villa, Gateshead Road, Jarrow.
1859. Price-Williams, Richard, 38 Parliament Street, Westminster, S.W.
1875. Prior, Johannes Andreas, 33 Bredgade, Copenhagen.
1874. Prosser, William Henry, Messrs. Harfield and Co., Mansion House Buildings, Queen Victoria Street, London, E.C.
1875. Provis, George Stanton, Ingoldsby, Belvedere Road, Upper Norwood, London, S.E.
1885. Pudan, Oliver, Manager, Locomotive and Carriage Works, Riazan and Kosloff Railway, Kosloff, Russia.
1884. Puplett, Samuel, 59 Colmore Row, Birmingham. [*Ice, Birmingham.*]
1866. Putnam, William, Darlington Forge, Darlington.

1878. Quillacq, Augustus de, Société anonyme de Constructions mécaniques d'Anzin, Anzin (Nord), France.

1873. Radcliffe, Arthur Henry Wright, 5 Carr's Lane, Birmingham.
1870. Radcliffe, William, Camden House, 25 Collegiate Crescent, Sheffield.
1878. Radford, Richard Heber, 15 St. James' Row, Sheffield.
1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.
1884. Rafarel, William Claude, Barnstaple Foundry and Engineering Works, Victoria Road, Barnstaple.
1885. Rainforth, William, Jun., Britannia Iron Works, Lincoln. [*Rainforths, Lincoln.*]
1878. Rait, Henry Milnes, Messrs. Rait and Gardiner, 155 Fenchurch Street, London, E.C.
1847. Ramsbottom, John, Fernhill, Alderley Edge, Cheshire.

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1866. Ramsden, Sir James, Abbot's Wood, Barrow-in-Furness.
1860. Ransome, Allen, 304 King's Road, Chelsea, London, S.W.
1869. Ransome, Robert Charles, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich.
1862. Ransome, Robert James, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich.
1873. Rapier, Richard Christopher, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich; and 5 Westminster Chambers, Victoria Street, Westminster, S.W.
1883. Rathbone, Edgar Philip, Mining Engineer, 2 Great George Street, Westminster, S.W. [*Busera, London.* 3117.]
1867. Ratliffe, George, 81 Cannon Street Buildings, 139 Cannon Street, London, E.C.
1862. Ravenhill, John R., 27 Courtfield Gardens, South Kensington, London, S.W.
1872. Rawlins, John, Manager, Metropolitan Railway-Carriage and Wagon Works, Saltley, Birmingham. [*Metro, Birmingham.*]
1878. Rawlinson, Sir Robert, C.B., Chief Inspector, Local Government Board, Whitehall, London, S.W.
1883. Reader, Reuben, Phœnix Works, Cremorne Street, Nottingham.
1882. Reay, Thomas Purvis, Messrs. Kitson and Co., Airedale Foundry, Leeds.
1881. Redpath, Francis Robert, Canada Sugar Refinery, Montreal, Canada.
1883. Reed, Alexander Henry, 90 Cannon Street, London, E.C. [*Wagon, London.*]
1881. Reed, Charles Holloway, Trimdon Iron Works, Sunderland. [*Chreed, Sunderland.* 17.]
1870. Reed, Sir Edward James, K.C.B., M.P., F.R.S., Broadway Chambers, Westminster, S.W.
1884. Rees, William David, Swansea Railway-Carriage and Wagon Works, Swansea.
1884. Rees, William Thomas, Mining Engineer, Gadlys Cottage, Aberdare.
1883. Reid, James, Messrs. Neilson and Co., Hyde Park Locomotive Works, Glasgow.
1859. Rennie, George Banks, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.; and 20 Lowndes Street, Lowndes Square, London, S.W.
1879. Rennie, John Keith, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.
1881. Rennoldson, Joseph Middleton, Marine Engine Works, South Shields. [*Rennoldson, South Shields.* 11.]
1876. Restler, James William, Engineer, Southwark and Vauxhall Water Works, Sumner Street, Southwark, London, S.E.
1883. Reunert, Theodore, Kimberley, South Africa; and Benson's Buildings, Park Row, Leeds.

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1862. Reynolds, Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1879. Reynolds, George Bernard, Assistant Manager, Wardha Coal State Railway, Warora, Central Provinces, India.

1882. Rhodes, Vincent, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.

1875. Rich, William Edmund, Engineer, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.

1866. Richards, Edward Windsor, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough.

1882. Richards, George, Messrs. George Richards and Co., Atlantic Works, Broadheath, near Manchester.

1856. Richards, Josiah, Pontypool Iron and Tinplate Works, Pontypool.

1884. Richards, Lewis, Dowlais Iron and Steel Works, Dowlais.

1863. Richardson, The Hon. Edward, C.M.G., Minister of Public Works, Christchurch, Canterbury, New Zealand.

1865. Richardson, John, Methley Park, near Leeds.

1873. Richardson, John, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1859. Richardson, William, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1884. Riches, Charles Hurry, Assistant Locomotive Superintendent, Taff Vale Railway, Cardiff.

1874. Riches, Tom Hurry, Locomotive Superintendent, Taff Vale Railway, Cardiff. [*Locomotive, Cardiff.*]

1873. Rickaby, Alfred Austin, Bloomfield Engine Works, Sunderland. [*Rickaby, Sunderland.*]

1879. Ridley, James Cartmell, Queen Street, Newcastle-on-Tyne.

1863. Rigby, Samuel, Fern Bank, Liverpool Road, Chester.

1874. Riley, James, General Manager, Steel Company of Scotland, 150 Hope Street, Glasgow.

1879. Rixom, Alfred John, Woodstone Steam Brick and Tile Works, Peterborough; and 38 The Grove, Hammersmith, London, W.

1879. Roberts, Thomas Herbert, Mechanical Superintendent, Chicago and Grand Trunk Railway, Detroit, Michigan, United States.

1848. Robertson, Henry, M.P., Great Western Railway, Shrewsbury; and 13 Lancaster Gate, London, W.; and Palé, Corwen.

1879. Robertson, William, Messrs. Boyd and Co., Engineers and Shipbuilders, Shanghai, China: (or care of Herbert J. Stockton, 46 Queen Victoria Street, London, E.C.)

1883. Robins, Edward, Assistant Engineer, Public Works Department, 62 Brickdam, George Town, Demerara, British Guiana: (or care of Charles Robins, 3 Holmdale Road, Denington Park, West Hampstead, London, N.W.)

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1874. Robinson, Henry, 7 Westminster Chambers, Victoria Street, Westminster, S.W.

1876. Robinson, James Salkeld, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.

1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester; and Westwood Hall, Leek, near Stoke-upon-Trent.

1878. Robinson, John Frederick, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.

1878. Robinson, Thomas Neild, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.

1866. Robson, Thomas, Mining Engineer, Lumley Thicks, Fence Houses.

1879. Rodger, William, care of Messrs. Ralli Brothers, Bombay: (or care of Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow.)

1884. Rodrigues, José Maria de Chermont, Rua de S. Pedro 54 sobrado, Rio de Janeiro, Brazil: (or care of Messrs. Jacob Walter and Co., 34 Leadenhall Street, London, E.C.)

1872. Rofe, Henry, Cavendish Hill, Sherwood, Nottingham.

1885. Rogers, Henry John, Watford Iron Works, Watford. [*Engineer, Watford.*]

1868. Rogers, William, Sergipe, care of Messrs. Hugh Wilson and Son, Bahia, Brazil: (or care of J. Kenyon Rogers, 25 Water Street, Liverpool.)

1871. Rollo, David, Messrs. David Rollo and Sons, Fulton Engine Works, 10 Fulton Street, Liverpool.

1874. Ross, John Alexander George, 46 Grainger Street West, Newcastle-on-Tyne.

1881. Ross, William, Messrs. Ross and Walpole, North Wall Iron Works, Dublin. [*Iron, Dublin.* 311.]

1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Peterborough.

1878. Routh, William Pole, 25 Rua de S. Francisco, Oporto, Portugal: (or care of Cyril E. Routh, St. Michael's House, Cornhill, London, E.C.)

1880. Routledge, Thomas, Ford Paper Works, Sunderland; and Claxheugh, Sunderland.

1878. Russell, The Hon. William, George Town, Demerara, British Guiana; and 65 Holland Park, London, W.

1867. Ruston, Joseph, M.P., Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln; and 6 Onslow Gardens, South Kensington, London, S.W.

1884. Rutherford, George, Manager, Wallsend Slipway and Engineering Works, Cardiff. [*Wall, Cardiff.*]

1877. Rutter, Edward, The Cedars, Richmond, Surrey.

1885. Ryan, John, D.Sc., Professor of Physics and Engineering, University College, Bristol.

1883. Ryder, George, Turner Bridge Iron Works, Tong, near Bolton. [*Ryder, Bolton.* 33A.]

1866. Ryland, Frederick, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich.

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1866. Sacré, Alfred Louis, 60 Queen Victoria Street, London, E.C. [*Sextant, London.* 1668.]

1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Manchester; and Sunnyside, Victoria Park, Manchester.

1883. Sadoine, Baron Eugène, Société Cockerill, Seraing, Belgium.

1864. Said, Colonel M., Pasha, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 9 Park Crescent, Portland Place, London, W.)

1859. Salt, George, Sir Titus Salt, Bart., Sons and Co., Saltaire, near Bradford; and Royal Thames Yacht Club, 7 Albemarle Street, London, W.

1874. Sampson, James Lyons, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N. [*Bascule, London.* 6699.]

1864. Samuda, Joseph D'Aguilar, Iron Ship Building Yard, Isle of Dogs, Poplar, London, E.

1865. Samuelson, Sir Bernhard, Bart., M.P., F.R.S., Britannia Iron Works, Banbury; and 56 Prince's Gate, South Kensington, London, S.W.; and Lupton, Brixham, South Devon.

1881. Samuelson, Ernest, Messrs. Samuelson and Co., Britannia Iron Works, Banbury.

1881. Sanders, Henry Conrad, Messrs. H. G. Sanders and Son, Victoria Works, Victoria Gardens, Notting Hill Gate, London, W.; and 7 Boscombe Road, Shepherd's Bush, London, W.

1871. Sanders, Richard David, North Berwick.

1881. Sandiford, Charles, Locomotive Superintendent, Scinde Punjaub and Delhi Railway, Lahore, Punjaub, India.

1874. Sauvée, Albert, 22 Parliament Street, Westminster, S.W. [*Sauvée, London.* 3133.]

1882. Sawyer, Frederic Henry Read, 18 Calle Real de San Miguel, Manila, Philippine Islands; and 56 Gresham Road, Brixton, London, S.W.

1880. Saxby, John, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W.

1869. Scarlett, James, Messrs. E. Green and Son, 14 St. Ann's Square, Manchester.

1883. Schönheyder, William, 81 St. Stephen's Avenue, Shepherd's Bush, London, W.

1880. Schram, Richard, 9 Northumberland Street, Strand, London, W.C. [*Schram, London.*]

1885. Scorgie, James, Professor of Applied Mechanics, Civil Engineering College, Poona, India: (or care of Messrs. W. Watson and Co., 27 Leadenhall Street, London, E.C.).

1876. Scott, David, Port Commissioners' Office, Calcutta.

1875. Scott, Frederick Whitaker, Atlas Steel and Iron Wire Rope Works, Reddish, Stockport. [*Atlas, Reddish.*]

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1881. Scott, George Innes, 4 Queen Street, Newcastle-on-Tyne.
1877. Scott, Irving M., Messrs. Prescott Scott and Co., Union Iron Works, San Francisco, California.
1881. Scott, James, care of Messrs. Steel Murray and Co., Merchants, Durban, Natal : (or care of Mr. Wallace, The Home Farm, Murthly, Perthshire.)
1884. Scott, John, Messrs. Charles Hill and Sons, Bristol.
1885. Scott, Robert, Engineer, Messrs. Takata and Co., Tsukiji, Tokio, Japan.
1861. Scott, Walter Henry, Park Road, East Molesey, Kingston-on-Thames.
1884. Scott-Moncrieff, William Dundas, 4D Upper Baker Street, London, N.W.
1868. Scriven, Charles, Messrs. Scriven and Co., Leeds Old Foundry, Marsh Lane, Leeds; and Whinfield Mount, Chapel Allerton, Leeds.
1882. Seabrook, Alfred William, Engineer Surveyor to the Port of Bombay, Port Office, Bombay; and 2 Weedon Terrace, Lower Woolwich Road, East Greenwich, S.E.
1882. Seaton, Albert Edward, Earle's Shipbuilding and Engineering Works, Hull.
1864. Seddon, John, 98 Wallgate, Wigan.
1857. Selby, George Thomas, Woolton Hill, Newbury.
1882. Selfe, Norman, 141 Pitt Street, Sydney, New South Wales.
1884. Sellers, Coleman, Messrs. William Sellers and Co., 1600 Hamilton Street, Philadelphia; and 3301 Baring Street, Philadelphia, Pennsylvania, United States.
1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennsylvania, United States.
1881. Sennett, Richard, Admiralty, Whitehall, London, S.W.
1883. Shackleford, Arthur Lewis, General Manager, Britannia Railway-Carriage and Wagon Works, Saltley, Birmingham.
1884. Shackleford, William Copley, Manager, Lancaster Wagon Works, Lancaster.
1872. Shanks, Arthur, Messrs. A. Burn and Co., Howrah Iron Works, Howrah; and 7 Hastings Street, Calcutta.
1884. Shanks, William, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]
1881. Shanks, William Weallens, 18 Strand Road, Howrah, Bengal.
1881. Shapton, William, Sir William G. Armstrong Mitchell and Co., 8 Great George Street, Westminster, S.W.
1863. Sharp, Henry, Bolton Iron and Steel Works, Bolton.
1875. Sharp, Thomas Budworth, Managing Engineer, Muntz Metal Works, Birmingham.
1867. Sharpe, Charles James, 27 Great George Street, Westminster, S.W.
1869. Sharrock, Samuel, Windsor Iron Works, Garston, near Liverpool; and 8 Old Jewry, London, E.C.
1882. Sharrock, Samuel Lord, Hydraulic Engineering Works, Chester.
1864. Shaw, Duncan, Mining Engineer, Cordoba, Spain.

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1879. Shaw, Henry Selby Hele, Professor of Engineering, University College, Bristol.

1881. Shaw, Joshua, Messrs. John Shaw and Sons, Wellington Street Works, Salford, Manchester.

1881. Shaw, William, Jun., Stanners Closes Steel Works, Wolsingham, near Darlington.

1856. Shelley, Charles Percy Bysshe, 45 Parliament Street, Westminster, S.W.

1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.

1875. Sheppard, Herbert Gurney, East Indian Railway, Cawnpore, India; and 89 Westbourne Terrace, Hyde Park, London, W.

1876. Shield, Henry, Messrs. Fawcett Preston and Co., Phœnix Foundry, 17 York Street, Liverpool.

1872. Shoolbred, James Nelson, 3 Westminster Chambers, Victoria Street, Westminster, S.W.

1885. Shuttleworth, Alfred, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln.

1885. Shuttleworth, Major Frank, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln; and Old Warden Park, Biggleswade.

1871. Simon, Henry, 20 Mount Street, Manchester. [*Henry Simon, Manchester.*]

1877. Simonds, William Turner (*Life Member*), Messrs. J. C. Simonds and Son, Oil Mills, Boston.

1873. Simpson, Alfred, 11 High Street, Hull; and Denmark House, Alexandra Road, St. John's Wood, near Hull.

1876. Simpson, Arthur Telford, Engineer, Chelsea Water Works, 38 Parliament Street, Westminster, S.W.

1878. Simpson, James, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.

1885. Simpson, James Thomas, Executive Engineer, Calcutta Workshops Division, Civil Engineering College, Seebpore, Calcutta.

1882. Simpson, John Harwood, Severn Tunnel Works, Portskewett, near Chepstow.

1847. Sinclair, Robert, care of Messrs. Sinclair Hamilton and Co., 17 St. Helen's Place, Bishopsgate Street, London, E.C.

1857. Sinclair, Robert Cooper, 3 Adelaide Place, London Bridge, London, E.C.

1881. Sisson, William, Messrs. Cox and Co., Falmouth Docks Engine and Shipbuilding Works, Falmouth. [*Sisson, Falmouth.*]

1885. Sivewright, George William, Messrs. Withy and Co., Middleton Ship Yard, West Hartlepool.

1872. Slater, Alfred, Gloucester Wagon Works, Gloucester.

1859. Slater, Isaac, Gloucester Wagon Works, Gloucester.

1853. Slaughter, Edward, 7 Victoria Square, Clifton, Bristol.

1835. Slight, William Hooper, Alkmonton Vicarage, Derby.

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1879. Smith, Allison Dalrymple, Locomotive Superintendent, Canterbury Railways, Christchurch, New Zealand.

1879. Smith, Charles Hubert, Engineer and Shipwright Surveyor to the Board of Trade, North Shields.

1866. Smith, Edward Fisher, The Priory Offices, Dudley.

1866. Smith, George Fereday, Grovehurst, Tunbridge Wells. [*Grovehurst, Pembury, Kent.*]

1860. Smith, Henry, Messrs. Hill and Smith, Brierley Hill Iron Works, Brierley Hill; and Summerhill, Kingswinford, near Dudley.

1881. Smith, Henry, Messrs. Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.

1860. Smith, John, Parkfield, Duffield Road, Derby.

1876. Smith, John, Wintoun Terrace, Rochdale.

1883. Smith, John Bagnold, Langwith Colliery, near Mansfield.

1857. Smith, Josiah Timmis, Hæmatite Iron and Steel Works, Barrow-in-Furness.

1870. Smith, Michael Holroyd, Royal Insurance Buildings, Crossley Street Halifax.

1881. Smith, Robert Henry, Professor of Engineering, Mason Science College, Birmingham; and 10 St. Augustine's Road, Edgbaston, Birmingham.

1885. Smith, Thomas, Steam Crane Works, Old Foundry, Rodley, near Leeds. [*Tomsmith, Leeds.*]

1882. Smith, Walter Parker, 1 Roseford Gardens, Shepherd's Bush Green, London, W.

881. Smith, Wasteneys, 59 Sandhill, Newcastle-on-Tyne. [*Wasteneys Smith, Newcastle-on-Tyne.* 429.]

1863. Smith, William Ford, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester.

1882. Smyth, James Josiah, Messrs. James Smyth and Sons, Peasenhall, Suffolk.

1884. Smyth, William Stopford, Engineer, Alexandra Docks, Newport, Monmouthshire.

1883. Snelus, George James, West Cumberland Iron and Steel Works, Workington.

1885. Snowdon, John Armstrong, Maxim Gun Factory, 57D Hatton Garden, London, E.C.

1859. Sokoloff, Major-General Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt, Russia: (or care of Messrs. W. Collier and Co., Worsley Street, New Bailey Street, Salford, Manchester.)

1878. Sopwith, Thomas, Mining Engineer, 6 Great George Street, Westminster, S.W. [*Sopwith, London.* 3175.]

1884. Soulsby, James Charlton, Manager, Swansea Dry Docks and Engineering Works, 64 Mansel Terrace, Swansea.

1885. Southwell, Frederick Charles, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.

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1877. Soyres, Francis Johnstone de, Messrs. Bush and De Soyres, Bristol Iron Foundry, Bristol.

1878. Spencer, Alfred G., Messrs. George Spencer and Co., 77 Cannon Street, London, E.C.

1866. Spencer, Eli, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham; and The Knoll, Fulshaw Park, Wilmslow, near Manchester.

1878. Spencer, George, Messrs. George Spencer and Co., 77 Cannon Street, London, E.C.

1877. Spencer, John, Globe Tube Works, Wednesbury [*Tubes, Wednesbury.*]; and 3 Queen Street Place, Cannon Street, London, E.C. [*Tubes, London.*]

1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne.

1885. Spencer, Mountford, Slack's Emery Wheel and Machine Making Co., Lime Bank Street, Ardwick, Manchester.

1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.

1876. Spice, Robert Paulson, 21 Parliament Street, Westminster, S.W.

1862. Stableford, William, Broadwell House, Oldbury, near Birmingham.

1869. Stabler, James, 13 Effra Road, Brixton, London, S.W.

1880. Stafford, George, 17 Russell Street, Nottingham.

1877. Stanger, George Hurst, Queen's Chambers, North Street, Wolverhampton.

1875. Stanger, William Harry, 23 Queen Anne's Gate, Westminster, S.W.

1884. Stanton, Frederic Barry, General Manager, Railway-Carriage Works, Oldbury, near Birmingham.

1866. Stephens, John Classon, Messrs. Stephens and Co., Vulcan Iron Works, Sir John Rogerson's Quay, Dublin.

1874. Stephens, Michael, Locomotive Superintendent, Cape Government Railways, Cape Town, Cape of Good Hope.

1868. Stephenson, George Robert, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1879. Stephenson, Joseph Gurdon Leycester, 6 Drapers' Gardens, Throgmorton Street, London, E.C.

1876. Sterne, Louis, Messrs. L. Sterne and Co., Crown Iron Works, Glasgow [*Crown, Glasgow.*]; and 2 Victoria Mansions, Victoria Street, Westminster, S.W. [*Elsterne, London.* 3066.]

1875. Stevens, Arthur James, Uskside Iron Works, Newport, Monmouthshire.

1878. Stevenson, George Wilson, 38 Parliament Street, Westminster, S.W.

1877. Stewart, Alexander, Manager, Messrs. Thwaites Brothers, Vulcan Iron Works, Thornton Road, Bradford.

1878. Stewart, Duncan, Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow.

1851. Stewart, John, Blackwall Iron Works, Poplar, London, E.

1885. Stewart-Hamilton, Patrick, North Shields and District Tramways, North Shields.

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1880. Stirling, James, Locomotive Superintendent, South Eastern Railway, Ashford, Kent.

1885. Stirling, Matthew, Locomotive Superintendent, Hull Barnsley and West Riding Junction Railway and Dock Co., Hull.

1867. Stirling, Patrick, Locomotive Superintendent, Great Northern Railway, Doncaster.

1875. Stoker, Frederick William, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow.

1877. Stokes, Alfred Allen, The White House, Pauntley, Newent, Gloucestershire.

1877. Stothert, George Kelson, Steam Ship Works, Bristol.

1884. Stronge, Charles, Great Southern Railway, Locomotive Department, Buenos Aires; Post Office, Buenos Aires, Argentine Republic.

1865. Stroudley, William, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton; and Bosvigo, Preston Park, Brighton.

1873. Strype, William George, The Murrough, Wicklow. [*Strype, Wicklow.*]

1878. Stuart, James, M.P., Professor of Mechanism in Cambridge University, Trinity College, Cambridge.

1882. Sturgeon, John, 3 Westminster Chambers, Victoria Street, Westminster, S.W.

1882. Sugden, Thomas, Chadderton Iron Works, Irk Vale, Chadderton, near Manchester.

1861. Sumner, William, 2 Brazennose Street, Manchester.

1875. Sutcliffe, Frederic John Ramsbottom, Engineer, Low Moor Iron Works, near Bradford.

1883. Sutton, Joseph Walker, Messrs. Van Gelder Apsimon and Co., Victoria Works, Sowerby Bridge.

1880. Sutton, Thomas, Carriage and Wagon Superintendent, Furness Railway, Barrow-in-Furness.

1882. Swaine, John, Steel Company of Scotland, Newton, near Glasgow.

1884. Swan, Joseph Wilson, 57 Holborn Viaduct, London, E.C.

1882. Swinburne, William, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne.

1864. Swindell, James Swindell Evers, 16 and 17 Exchange Buildings, Stephenson Place, Birmingham; and Clent House, Stourbridge.

1878. Taite, John Charles, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C. [1618.]

1882. Tandy, John O'Brien, London and North Western Railway, Locomotive Department, Crewe.

1875. Tangye, George, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham.

1861. Tangye, James, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham; and Aviary Cottage, Illogan, near Redruth.

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1879. Tartt, William, Maythorn, Blindley Heath, Godstone, near Red Hill.
1876. Taunton, Richard Hobbs, Messrs. Taunton and Hayward, Star Tube Works, Heneage Street, Birmingham.
1882. Tayler, Alexander James Wallis, 63 Victoria Road, Kilburn, London, N.W.
1874. Taylor, Arthur, Manager, Lahat Tin Mines, Perak, viâ Penang; and 6 Queen Street Place, Upper Thames Street, London, E.C.
1874. Taylor, Henry Enfield, Mining Engineer, 15 Newgate Street, Chester.
1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead. [*Britannia, Birkenhead.* 4015.]
1873. Taylor, John, Midland Foundry, Queen's Road, Nottingham.
1867. Taylor, Joseph, Corinthian Villa, Acock's Green, near Birmingham.
1875. Taylor, Joseph Samuel, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham.
1874. Taylor, Percyvale, Messrs. Burthe and Taylor, 26 Rue de Caumartin, Paris.
1882. Taylor, Robert Henry, Clare Villa, Hale's Road, Cheltenham. [*Taylor, Clareville, Cheltenham.*]
1882. Taylor, Thomas Albert Oakes, Messrs. Taylor Brothers and Co., Clarence Iron Works, Leeds.
1883. Taylor, William, Midland Foundry, Queen's Road, Nottingham.
1876. Taylor, William Henry Osborne, Salford Villa, 12 Elm Grove, Peckham Rye, London, S.E.
1864. Tennant, Sir Charles, Bart., M.P. (*Life Member*), The Glen, Innerleithen, near Edinburgh.
1882. Terry, Stephen Harding, Local Government Board, Whitehall, London, S.W.
1877. Thom, William, Messrs. W. and J. Yates, Canal Foundry, Blackburn.
1867. Thomas, Joseph Lee, 16 Holland Road, Kensington, London, W.
1864. Thomas, Thomas, 10 Richmond Road, Roath, Cardiff.
1874. Thomas, William Henry, 15 Parliament Street, Westminster, S.W.
1875. Thompson, John, Highfields Boiler Works, Ettingshall, near Wolverhampton.
1883. Thompson, Richard Charles, Messrs. Robert Thompson and Sons, Southwick Shipbuilding Yard, Sunderland.
1857. Thompson, Robert, Victoria Chambers, Wigan; and Standish, near Wigan.
1880. Thompson, Thomas William, Messrs. Thompson and Gough, South Mersey Ferries, Birkenhead.
1879. Thomson, David, Craighead, West Heath, Belvedere, Kent.
1875. Thomson, James McIntyre, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow.
1868. Thomson, John, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow.
1880. Thornbery, William Henry, Jun., Corporation Chambers, 121 Colmore Row, Birmingham.

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1868. Thornewill, Robert, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1885. Thornley, George, Messrs. Buxton and Thornley, Waterloo Engineering Works, Burton-on-Trent.

1877. Thornton, Frederic William, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1882. Thornton, Hawthorn Robert, Lancashire and Yorkshire Railway, Locomotive Department, Victoria Station, Manchester.

1876. Thornycroft, John Isaac, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.

1882. Thow, William, Locomotive Superintendent, South Australian Railways, Adelaide, South Australia: (or care of Joseph Meilbek, 7 Westminster Chambers, Victoria Street, Westminster, S.W.)

1884. Thwaites, Arthur Hirst, Vulcan Iron Works, Bradford.

1885. Tijou, William, Ekman Pulp and Paper Co., 57½ Old Broad Street, London, E.C.; and 26 Arthur Road, Holloway, London, N.

1885. Timmermans, François, Engineer, Marcinelle and Couillet Iron Works, Couillet, Belgium. [*Timmermans, Couillet, Belgium.*]

1884. Timmis, Illius Augustus, 2 Great George Street, Westminster, S.W. [*Timmis, London.*]

1875. Tomkins, William Steele, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.

1857. Tomlinson, Joseph, Jun., 64 Priory Road, West Hampstead, London, N.W.

1867. Tonks, Edmund, Brass Works, Moseley Street, Birmingham.

1883. Tower, Beauchamp, 19 Great George Street, Westminster, S.W.

1883. Trentham, William Henry, 33 Portland Road, Notting Hill, London, W.

1876. Trevithick, Richard Francis, Locomotive Superintendent, Ceylon Government Railways, Colombo, Ceylon: (or care of Mrs. Mary Trevithick, The Cliff, Penzance.)

1873. Trow, Joseph, Messrs. William Trow and Sons, Union Foundry, Wednesbury; and Victoria House, Holyhead Road, Wednesbury.

1885. Trueman, Thomas Brynalyn, Sola Works, Ferro Carril del Sud, Buenos Aires, Argentine Republic: (or care of T. R. Trueman, 7 Cambridge Villas, Twickenham.)

1883. Turnbull, Charles Henry, Mersey Dock Estate, Dock Yard, Liverpool.

1885. Turnbull, John, Jun., 255 Bath Street, Glasgow. [*Turbine, Glasgow.*]

1884. Turner, Albert Harrison, 18 Provost Road, Haverstock Hill, London, N.W.

1866. Turner, Frederick, Messrs. E. R. and F. Turner, St. Peter's Iron Works, Ipswich. [*Gippeswyk, Ipswich.*]

1882. Turner, Thomas, New British Iron Works, Corngreaves, near Birmingham.

1876. Turney, John, Messrs. Turney Brothers, Trent Bridge Leather Works, Nottingham. [*Turney, Nottingham.*]

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1872. Turton, Thomas, Liverpool Forge Company, Brunswick Dock, Liverpool.
1867. Tweddell, Ralph Hart, 14 Delahay Street, Westminster, S.W. [*Tweddell, Westminster, London.*]
1882. Tweedy, John, Messrs. Wigham Richardson and Co., Newcastle-on-Tyne.
1856. Tyler, Sir Henry Whatley, K.C.B., M.P., Pymmes Park, Edmonton, Middlesex.
1877. Tylor, Joseph John, 11 Little Queen Street, Westminster, S.W.
1878. Tyson, Isaac Oliver, Ousegate Iron Works, Selby.

1875. Unsworth, Thomas, West Gorton Iron Works, Manchester. [*Machinist, Gorton.*]
1878. Unwin, William Cawthorne, Professor of Engineering, City and Guilds of London Central Institution, Exhibition Road, London, S.W.; and 7 Palace Gate Mansions, Kensington, London, W.
1875. Urquhart, Thomas, Locomotive Superintendent, Grazi and Tsaritsin Railway, Borisoglebsk, Russia: (or care of Walter Ross, Hill Top, Blythe Hill, Catford, London, S.E.)

1880. Valon, William Andrew McIntosh, Engineer, Corporation Gas and Water Works, Ramsgate. [*Valon, Ramsgate.*]
1885. Vaughan, William Henry, Royal Iron Works, West Gorton, Manchester. [*Pulleys, Openshaw.*]
1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.
1865. Vickers, Albert, Messrs. Vickers Sons and Co., River Don Works, Sheffield.
1861. Vickers, Thomas Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1883. Waddell, James, Superintending Engineer, Netherlands India Steam Navigation Co., Soerabaya, Java; and 13 Austin Friars, London, E.C.
1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.
1879. Wadia, Nowrosjee Nesserwanjee, Manockjee Petit Manufacturing Co., Tardeo, Bombay: (or care of Messrs. Hick Hargreaves and Co., Soho Iron Works, Bolton.) [*Wadia, Tardeo, Bombay.*]
1875. Wailes, John William, Patent Shaft Works, Wednesbury.
1884. Wailes, Thomas Waters, General Manager, Mountstuart Dry Dock and Engineering Works, Cardiff.
1881. Wake, Henry Hay, Engineer to the River Wear Commission, Sunderland.
1882. Wakefield, William, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Grand Canal Street, Dublin.
1873. Waldenström, Eric Hugo, Manager, Broughton Copper Works, Broughton Road, Manchester.

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1867. Walker, Benjamin, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds.

1877. Walker, David, Superintendent of Engineering Workshops, King's College, Strand, London, W.C.

1875. Walker, George, 95 Leadenhall Street, London, E.C.

1875. Walker, John Scarisbrick, Messrs. J. S. Walker and Brother, Pagefield Iron Works, Wigan; and 12 Ash Street, Southport.

1884. Walker, Sydney Ferris, 195 Severn Road, Cardiff [*Dynamo, Cardiff.*]; and Black Boy Yard, Nottingham. [*Dynamo, Nottingham.*]

1876. Walker, Thomas Ferdinand, Ship's Log Manufacturer, 58 Oxford Street, Birmingham.

1878. Walker, William, Kaliemaas, Alleyne Park, West Dulwich, London, S.E. [*Bromo, London.*]

1863. Walker, William Hugill, Messrs. Walker Eaton and Co., Wicker Iron Works, Sheffield.

1878. Walker, Zaccheus, Jun., Fox Hollies Hall, near Birmingham.

1881. Walkinshaw, Frank, Hartley Grange, Winchfield.

1884. Wallace, John, Backworth Collieries, near Newcastle-on-Tyne.

1884. Wallau, Frederick Peter, Messrs. Harland and Wolff, Belfast.

1868. Wallis, Herbert, Mechanical Superintendent, Grand Trunk Railway, Montreal, Canada.

1865. Walpole, Thomas, Messrs. Ross and Walpole, North Wall Iron Works, Dublin. [*Iron, Dublin.* 311.]

1877. Walton, James, 28 Maryon Road, Charlton.

1881. Warburton, John Seaton, 12 Lisgar Terrace, West Kensington, London, W.

1882. Ward, Thomas Henry, Messrs. Lee Howl Ward and Howl, Tipton.

1876. Ward, William Meese, Limerick Foundry, Great Bridge, Tipton.

1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Handsworth, near Birmingham. [*Bolts, Birmingham.*]

1856. Wardle, Charles Wetherell, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds.

1882. Wardle, Edwin, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds.

1852. Warham, John R., Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1881. Warham, Richard Landor, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1874. Warner, Edward, Messrs. Woods Cocksedge and Co., Suffolk Iron Works, Stowmarket.

1885. Warren, Henry John, Jun., Engineer-in-Chief, Venezuela Panama Gold Mine, Venezuela, South America: (or Hayle, Cornwall.)

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1885. Warren, William, Quebrada Railway Land and Copper Co., Tucacas; care of Messrs. Boulton and Co., Puerto Cabello, Venezuela, South America: (or care of Walter Ross, Hill Top, Blythe Hill, Catford, London, S.E.)

1882. Warsop, Henry, Clarendon Hotel, Nottingham.

1858. Waterhouse, Thomas (*Life Member*), Claremont Place, Sheffield.

1881. Watkins, Alfred, 2 Westcombe Park Road, Blackheath, London, S.E.

1862. Watkins, Richard, 94 Maida Vale, London, W.

1882. Watson, Henry Burnett, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne.

1879. Watson, William Renny, Messrs. Mirrlees Tait and Watson, Engineers, Glasgow.

1877. Watts, John, Broad Weir Engine Works, Bristol.

1877. Waugh, John, Chief Engineer, Yorkshire Boiler Insurance and Steam Users' Co., Sunbridge Chambers, Bradford.

1878. Weatherhead, Patrick Lambert, Maschinenbau Actien Gesellschaft Vulcan, Bredow bei Stettin, Germany: (or care of W. Weatherhead, Castlegate, Berwick-on-Tweed.)

1862. Webb, Francis William, Locomotive Superintendent, London and North Western Railway, Crewe.

1884. Webb, Richard George, International Exhibition, Office of Works, West Meadows, Edinburgh.

1883. Weck, Friedrich, Manager, Messrs. C. and W. Walker, Midland Iron Works, Donnington, near Newport, Shropshire.

1862. Wells, Charles, Moxley Iron and Steel Works, near Bilston.

1882. West, Charles Dickinson, Professor of Mechanical Engineering, Imperial College of Engineering, Tokio, Japan.

1876. West, Henry Hartley, Chief Surveyor, Underwriters' Registry for Iron Vessels, A13 Exchange Buildings, Liverpool.

1874. West, Nicholas James, Messrs. Harvey and Co., Hayle Foundry, Hayle.

1877. Western, Charles Robert, Broadway Chambers, Westminster, S.W. [*Donbowwow, London.* 3199.]

1877. Western, Maximilian Richard, care of Bombay Burmah Trading Corporation, Rangoon, British Burmah, India: (or care of Messrs. Western and Sons, 35 Essex Street, Strand, London, W.C.)

1862. Westmacott, Percy Graham Buchanan, Sir W. G. Armstrong Mitchell and Co., Elswick Engine Works, Newcastle-on-Tyne; and Benwell Hill, Newcastle-on-Tyne.

1880. Westmoreland, John William Hudson, Lecturer on Engineering, University College, Nottingham.

1867. Weston, Thomas Aldridge, Yale and Towne Manufacturing Co., 62 Reade Street, New York: (or care of J. C. Mewburn, 169 Fleet Street, London, E.C.)

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1880. Westwood, Joseph, Napier Yard, Millwall, London, E. [*Westwood, London.* 5065.]

1883. Wharton, Henry E., Engineering Manager, Basford Gas Works, Nottingham.

1881. Wharton, William Augustus, Assistant Engineer, Nottingham Corporation Water Works, St. Peter's Gate, Nottingham.

1884. Whieldon, John Henry, Campanhia do Beberibe, Rua Imperador, Pernambuco, Brazil: (or care of Ernest Whieldon, Gas Works, Oxford.)

1882. White, Alfred Edward, Borough Engineer's Office, Town Hall, Hull.

1874. White, Henry Watkins, 6 Hillsboro Road, East Dulwich Road, London, S.E.

1885. Whitehead, James George, Mechanical Engineer, Casilla No. 35, Callao, Peru.

1876. Whiteley, William, Messrs. William Whiteley and Sons, Prospect Iron Works, Lockwood, Huddersfield.

1884. Whithard, Brooke Middlemore, 18 Cockspur Street, London, S.W.

1863. Whitley, Joseph, New British Iron Works, Corngreaves, near Birmingham.

1865. Whitley, Joseph, Railway Works, Hunslet Road, Leeds.

1869. Whittem, Thomas Sibley, Wyken Colliery, Coventry.

1847. Whitworth, Sir Joseph, Bart., D.C.L., LL.D., F.R.S., Ashton Road, Openshaw, Manchester; Stancliffe, Matlock Bath; and 24 Great George Street, Westminster, S.W.

1878. Whytehead, Hugh Edward, North Staffordshire Tramways, Stoke-on-Trent.

1878. Wicks, Henry, Superintendent, Messrs. Burn and Co., Howrah Iron Works, Howrah, Bengal, India: (or care of Dr. Wicks, 1 Park Parade, Westmorland Road, Newcastle-on-Tyne.)

1868. Wicksteed, Joseph Hartley, Messrs. Joshua Buckton and Co., Well House Foundry, Meadow Road, Leeds.

1878. Widmark, Harald Wilhelm, Helsingborgs Mekaniska Verkstad, Helsingborg, Sweden.

1868. Wigram, Reginald, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1881. Wigzell, Eustace Ernest, 37 Walbrook, London, E.C.

1882. Wilder, John, Yield Hall Foundry, Reading.

1884. Wilkinson, William, Holme House Foundry, Wigan.

1885. Willcox, Francis William, 45 West Sunniside, Sunderland.

1874. Williams, David, Manager, Pontypool Iron and Tinplate Works, Pontypool.

1865. Williams, Edward, Cleveland Lodge, Middlesbrough.

1883. Williams, Edward Leader, Queen's Chambers, John Dalton Street, Manchester.

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1884. Williams, John Begby, Messrs. William Gray and Co., Central Marine Engineering Works, West Hartlepool.

1884. Williams, John Rhys, Rhymney Iron Works, Rhymney, R.S.O., Monmouthshire.

1885. Williams, Nicholas Thomas, Mining Engineer, Brazilian Exploration Co., 9 New Broad Street, London, E.C.

1847. Williams, Richard, Patent Shaft Works, Wednesbury.

1881. Williams, William Freke Maxwell, 35 Queen Victoria Street, London, E.C.

1873. Williams, William Lawrence, 2 Westminster Chambers, Victoria Street, Westminster, S.W. [*Snowdon, London.*]

1883. Williamson, Richard, Messrs. Richard Williamson and Son, Iron Shipbuilding Yard, Workington.

1870. Willman, Charles, Exchange Place, Middlesbrough.

1883. Willmott, Arthur Wellesley Westmacott, Kiangnan Arsenal, Shanghai, China.

1884. Willock, Capt. Harry Borlase, R.E., War Office, Whitehall, London, S.W.

1878. Wilson, Alexander, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.

1884. Wilson, Alexander, Addington House, Bow Road, London, E.

1882. Wilson, Alexander Basil, Holywood, Belfast. [*Wilson, Holywood.* 201.]

1872. Wilson, Alfred, Gas Furnace Engineer, Stafford. [*Wilson, Stafford.*]

1859. Wilson, George, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.

1883. Wilson, George Prangley, Assistant Manager, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.

1867. Wilson, Henry, Phœnix Brass Works, Stockton-on-Tees.

1884. Wilson, James, Chief Engineer of the Daira Sanieh, Egypt; Cairo, Egypt.

1881. Wilson, John, Engineer, Great Eastern Railway, Liverpool Street Station, London, E.C.

1863. Wilson, John Charles, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1879. Wilson, Joseph William, Principal of School of Practical Engineering, Crystal Palace, Sydenham, London, S.E.

1880. Wilson, Robert, 24 Poultry, London, E.C.

1883. Wilson, Robert, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester.

1884. Wilson, Thomas, Manager, Wallsend Slipway and Engineering Works, Wallsend, near Newcastle-on-Tyne.

1873. Wilson, Thomas Sipling, British Vice-Consul, Brettesnœs, Lofoten Islands, Norway; and Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Leeds: (or care of Messrs. James Bischoff and Sons, 10 St. Helen's Place, London, E.C.)

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1881. Wilson, Wesley William, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin.

1867. Winby, Frederick Charles, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1872. Winstanley, Robert, Mining Engineer, 28 Deansgate, Manchester.

1872. Wise, William Lloyd, 46 Lincoln's Inn Fields, London, W.C. [*Lloydwise, London.* 2766.]

1871. Withy, Edward, Avon Villa, Parnell, Auckland, New Zealand.

1884. Withy, Henry, Messrs. Withy and Co., Middleton Ship Yard, West Hartlepool. [*Withy, West Hartlepool.* 4.]

1878. Wolfe, John Edward, General Manager, Alagoas Railway, Maceio, Brazil: (or care of Rev. Prebendary Wolfe, Arthington, Torquay.)

1878. Wolfenden, Richard, Chief Engineer, Chinese Cruiser "Yang Wei"; care of Chinese Customs Agency, Hong Kong, China; and 11 Grafton Street, Moss Side, Manchester.

1878. Wolfenden, Robert, Revenue Cutter "Ling Fêng," care of Commissioner of Customs, Amoy, China.

1882. Wolff, John Frederick, 43 Lavender Sweep, Clapham Common, London, S.W.

1881. Wood, Edward Malcolm, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1868. Wood, Lindsay, Mining Engineer, Southhill, near Chester-le-Street.

1885. Wood, Robert Henry, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds.

1884. Wood, Sidney Prescott, care of H. W. Little, Messrs. McKenzie and Holland, Vulcan Iron Works, Worcester.

1876. Wood, Thomas, Mining Engineer, North Hetton Collieries, Fence Houses.

1885. Wood, Thomas, Ebbw Vale Steel Iron and Coal Works, Ebbw Vale, R.S.O., Monmouthshire.

1882. Woodall, Corbet, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1884. Woodward, William, Engineer and Manager, Corporation Gas Works, Bury, Lancashire. [*Woodward, Bury.*]

1885. Wootton, Albert, Falcon Engine and Car Works, Loughborough.

1874. Worsdell, Thomas William, Locomotive Superintendent, North Eastern Railway, Gateshead. [*Locomotive, Gateshead.*]

1884. Worssam, Charles Smith, Messrs. Samuel Worssam and Co., Oakley Works, Chelsea, London, S.W.

1877. Worssam, Henry John, Messrs. G. J. Worssam and Son, Wenlock Road, City Road, London, N. [*Mussrow, London.* 6656.]

1876. Worssam, Samuel William, Oakley Works, King's Road, Chelsea, London, S.W.

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1860. Worthington, Samuel Barton, Resident Engineer, London and North Western Railway, Victoria Station, Manchester; and 12 York Place, Oxford Road, Manchester.

1866. Wren, Henry, Messrs. Henry Wren and Co., London Road Iron Works, Manchester.

1881. Wrench, John Mervyn, Resident Engineer, Scinde Punjaub and Delhi Railway, Lahore, Punjaub, India.

1881. Wright, Benjamin Frederick, Locomotive and Carriage Superintendent, Japanese Government Railways, Kobe, Japan: (or care of Messrs. Malcolm Brunker and Co., 22 St. Mary Axe, London, E.C.)

1870. Wright, George Benjamin, Prince's Square, Wolverhampton.

1878. Wright, Rev. George Howard, 21 Clanricarde Gardens, Bayswater, London, W.

1876. Wright, James, Messrs. Ashmore Benson Pease and Co., Stockton-on-Tees. [*Wright, Gasholder, Stockton.* 12.]

1867. Wright, John Roper, Messrs. Wright Buttler and Co., Elba Steel Works, Gower Road, near Swansea.

1859. Wright, Joseph, Metropolitan Railway-Carriage and Wagon Co., Saltley Works, Birmingham; and 85 Gracechurch Street, London, E.C.

1860. Wright, Joseph, Neptune Forge, Chain and Anchor Works, Tipton; and Attercliffe, 42 Frederick Road, Edgbaston, Birmingham.

1878. Wright, William Barton, Locomotive Superintendent, Lancashire and Yorkshire Railway, Victoria Station, Manchester.

1871. Wrightson, Thomas, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.

1865. Wyllie, Andrew, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.

1883. Wyllie, Robert, Manager, Messrs. Thomas Richardson and Sons, Hartlepool Iron Works, Hartlepool.

1883. Wynne-Edwards, Thomas Alured, Agricultural Engineering Works Denbigh. [*Foundry, Denbigh.*]

1877. Wyvill, Frederic Christopher, 69 Old Street, London, E.C.

1878. Yates, Henry, Brantford, Ontario, Canada.

1882. Yates, Herbert Rushton, Assistant Engineer, Michigan Air Line Railway Extension, Pontiac, Michigan, United States: (or care of Henry Yates, Brantford, Ontario, Canada.)

1881. Yates, Louis Edmund Hasselts, Assistant Locomotive Superintendent, Northern Bengal State Railway, Saidpur, Bengal, India: (or care of Rev. H. W. Yates, 98 Lansdowne Place, Brighton.)

1880. Yates, William, Locomotive Works, Lancashire and Yorkshire Railway Miles Platting, Manchester.

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1885. Yeo, George Jope, Gas and Consulting Engineer, Shanghai, China; and The Vicarage, Edenfield, near Bury, Lancashire.

1880. York, Francis Colin, Buenos Aires and Pacific Railway, Mercedes, Buenos Aires, Argentine Republic: (or care of Messrs. Samuel York and Co., Snow Hill, Wolverhampton.)

1879. Young, George Scholey, Messrs. T. A. Young and Son, Orchard Place, Blackwall, London, E.

1874. Young, James, Managing Engineer, Lambton Colliery Works, Fence Houses.

1879. Young, James, Low Moor Iron Works, near Bradford.

1881. Younger, Robert, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1880. Ziffer, Ferdinand Henry, 12 Eisenbahn Strasse, Neupest, Budapest, Hungary.

1885. Zimmer, George Friedrich, care of J. Harrison Carter, 82 Mark Lane, London, E.C.

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ASSOCIATES.

1880. Allen, William Edgar, Imperial Steel Works, Savile Street, Sheffield.
1880. Bagshawe, Washington, Monk Bridge Iron Works, Leeds.
1881. Barcroft, Henry, Bessbrook Spinning Works, County Armagh, Ireland.
1879. Clowes, Edward Arnott, Messrs. William Clowes and Sons, Duke Street, Stamford Street, London, S.E. [*Clowes, London.* 4558.]
1867. Dewhurst, John Bonny, Bellevue Cotton Mills, Skipton.
1882. Drury, Robert Francis, George Street, Sheffield.
1883. Fairholme, Capt. Charles, R.N., Heberlein Self-acting Railway Brake Co., 18 St. Dunstan's Hill, London, E.C.
1883. Fung Yee, Secretary, Chinese Legation, 49 Portland Place, London, W.
1865. Gössell, Otto, 41 Moorgate Street, London, E.C.
1878. Grosvenor, The Right Hon. Lord Richard De Aquila, M.P., 12 Upper Brook Street, Grosvenor Square, London, W.
1880. Haggie, David Henry, Wearmouth Rope Works, Sunderland.
1884. Hasluck, Paul Nooncree, 309 Regent Street, London, W.
1884. Jackson, Edward, Midland Railway-Carriage and Wagon Works, Birmingham. [*Wagon, Birmingham.*]
1882. Jackson, William, Kingston Cotton Mill, Hull.
1859. Leather, John Towlerton (*Life Associate*), Leventhorpe Hall, near Leeds.
1884. Livesey, Joseph Montague, Stourton Hall, Horncastle; and Boyle Farm, Thames Ditton, Surrey.
1865. Longsdon, Alfred, 9 New Broad Street, London, E.C.
1881. Lowood, John Grayson, Gannister Works, Attercliffe Road, Sheffield.
1883. Macilraith, James, 182 Hope Street, Glasgow.
1868. Matthews, Thomas Bright, Messrs. Turton Brothers and Matthews, Phœnix Steel Works, Sheffield.
1885. Moser, Charles Henry, Messrs. Moser and Sons, 178 High Street, Southwark, London, S.E. [*Moserson, London.* 4563.]
1874. Paget, Berkeley, Low Moor Iron Office, 2 Laurence Pountney Hill, Cannon Street, London, E.C.
1865. Parry, David, Leeds Iron Works, Leeds.
1884. Phillips, Richard Morgan, care of Messrs. Emile Des Marets and Co., 14 Stone Street, New York, United States.
1877. Render, Frederick, 12 St. Mary Street, Deansgate, Manchester.
1882. Ridehalgh, George John Miller, Fell Foot, Newby Bridge, Ulverston.
1884. Ripper, William, Assistant Professor of Mechanical Engineering, Firth College, Sheffield.
1878. Roeckner, Carl Heinrich, 4 Royal Arcade, Newcastle-on-Tyne.

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1883. Sandham, Henry, Keeper, Science and Art Department, South Kensington Museum, London, S.W.

1875. Schofield, Christopher J., Vitriol and Alkali Works, Clayton, near Manchester.

1884. Tilfourd, George, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1869. Varley, John, Leeds Forge, Leeds.

1878. Watson, Joseph, Patent Office, 25 Southampton Buildings, London, W.C.

1883. Williamson, Robert S., Cannock and Rugeley Collieries, Hednesford, near Stafford.

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GRADUATES.

1884. Adam, Frank, Sir W. G. Armstrong Mitchell and Co., Elswick, Newcastle-on-Tyne.

1885. Addis, Frederick Henry, London and South Western Railway, Nine Elms, London, S.W.

1881. Alexander, Edward Disney, care of Rev. W. Hudson, Carlton Rectory, Worksop.

1885. Allcard, Harry, Messrs. Easterbrook Allcard and Wild, Albert Works, Penistone Road, Sheffield.

1874. Allen, Frank, Messrs. Allen Alderson and Co., Gracechurch Street, Alexandria: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1882. Allgood, Robert Lancelot, Ingram, Alnwick.

1885. Amos, Ewart Charles, Rosslyn Grove, Hampstead, London, N.W.

1880. Anderson, Edward William, Messrs. Easton and Anderson, Erith Iron Works, Erith, S.O., Kent.

1882. Anderson, William, North Eastern Railway, Locomotive Department, York.

1878. Appleby, Charles, Jun., Messrs. Appleby Brothers, 89 Cannon Street, London, E.C. [*Appleby's, London.* 1731.]; and East Greenwich Works, London, S.E.

1883. Appleby, Percy Vavasseur, Messrs. Appleby Brothers, East Greenwich Works, London, S.E.

1878. Armstrong, Joseph, Great Western Railway Works, Swindon.

1869. Bainbridge, Emerson, Nunnery Colliery Offices, New Haymarket, Sheffield.

1882. Barstow, Thomas Hulme, Railway Manager, Picton, Marlborough, New Zealand.

1881. Beesley, David Stanley, Messrs. D. S. Beesley and Co., 89 Dartmouth Street, Birmingham.

1884. Bell, Robert Arthur, Kew, Surrey.

1880. Birkett, Herbert, Messrs. J. and E. Hall, Iron Works, Dartford.

1884. Bocquet, Harry, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1883. Booth, William Stanway, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire.

1882. Bowles, Edward Wingfield, 86 Cambridge Street, Pimlico, London, S.W.

1878. Brooke, Arthur, General Post Office, Auckland, New Zealand; and Sunnymead, The Rise, Sidcup, S.O., Kent.

1880. Buckle, William Harry Ray, Union Dock, Limehouse, London, E. [*Buckle, Fletchdock, London.* 5109.]

1879. Burnet, Lindsay, Moore Park Boiler Works, Govan, near Glasgow. [*Burnet, Glasgow.* 1513.]

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1885. Burrowes, Gerald Vaughan, 61 Palace Gardens Terrace, London, W.

1884. Butler, Hugh Myddleton, Kirkstall Forge, near Leeds.

1883. Cairns, The Hon. Herbert John, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne.

1885. Clarke, Leslie, Eccleston Iron Works, Pimlico, London, S.W.

1883. Clench, Frederick McDakin, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1881. Clench, Gordon McDakin, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1885. Clift, Leslie Everitt, Fernbank, Pittville, Cheltenham.

1885. Clifton, George Bellamy, Great Western Railway Works, Swindon.

1883. Clinkskill, Alfred Alphonse Rouff, 1 Holland Place, St. Vincent Street, Glasgow.

1883. Cotton, Henry Streatfeild, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.; and 25 Vincent Square, Westminster, S.W.

1883. Cowan, Henry John Franklin, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1885. Crosta, Lorenzo William, Messrs. R. R. Newlove and Co., Crown Iron Works, Crocus Street, Nottingham; and 21 Mayfield Grove, Nottingham.

1876. Davis, Joseph, Lancashire and Yorkshire Railway, Engineer's Office, Manchester.

1875. Dawson, Edward, Messrs. Forster Brown and Rees, Guild Hall Chambers, Cardiff.

1884. Dixon, John, 115 York Place, Harpurhey, R. O., Manchester.

1868. Dugard, William Henry, Messrs. Dugard Brothers, Vulcan Rolling Mills, Bridge Street West, Summer Lane, Birmingham.

1885. Dutt, Jodoo Nauth, 8 Mecklenburgh Street, London, W.C.

1885. Edwards, Walter Cleeve, Assistant Engineer, Wellington and Manawatu Railway, Wellington, New Zealand.

1875. Ffolkes, Martin William Brown, 28 Davies Street, Grosvenor Square, London, W.

1883. Gibbons, Charles Kenrick, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne.

1885. Grant, John Macpherson, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne; and 63 Westmorland Road, Newcastle-on-Tyne.

1878. Greig, Alfred, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1885. Head, Archibald Potter, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne; and 23 North View, Heaton, near Newcastle-on-Tyne.

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1882. Heath, Ashton Marler, London and South Western Railway, Locomotive Department, Nine Elms, London, S.W.

1877. Heaton, Arthur, Messrs. Heaton and Dugard, Metal and Wire Works, Shadwell Street, Birmingham. [*Heagard, Birmingham.*]

1874. Hedley, Thomas, 118 Holt Road, Liverpool.

1883. Hill, John Kershaw, Engineer and Manager, West Surrey Water Works, High Street, Walton-on-Thames.

1867. Holland, George, Mechanical Department, Grand Trunk Railway, Montreal, Canada.

1885. Holroyd, John Herbert, care of Mrs. Collinson, 1 The Woodlands, Victoria Park, Manchester.

1884. Holt, Follett, London and South Western Railway, Locomotive Department, Nine Elms, London, S.W.

1883. Howard, Harry James, Messrs. Colman's Mustard Mills, Carrow Works, Norwich.

1879. Howard, J. Harold, Britannia Iron Works, Bedford.

1883. Hulse, Joseph Whitworth, Messrs. Hulse and Co., Ordsal Tool Works, Regent Bridge, Salford, Manchester.

1880. Jenkins, Rhys, Patent Office, 25 Southampton Buildings, London, W.C.

1883. Keen, Francis Watkins, Patent Nut and Bolt Works, Smethwick, near Birmingham.

1885. Keyworth, Thomas Egerton, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln; and 38 Monks Road, Lincoln.

1884. King, Charles Philip, 80 Fernhead Road, Westbourne Park, London, W.

1885. Laidler, Thomas, Messrs. J. and E. Wright, Universe Rope Works, Millwall, London, E. [*Gravitation, London.*]

1883. Lander, Philip Vincent, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.

1881. Lawson, James Ibbs, New Zealand Railways, Dunedin, Otago, New Zealand.

1884. Lepan, René, Lead and Tin Rolling Mills and Pipe Works, Lille (Nord), France.

1879. Lowthian, George, 58 Blenheim Crescent, Notting Hill, London, W.

1881. Macdonald, Ranald Mackintosh, Messrs. Booth Macdonald and Co., Carlyle Engineering and Implement Works, Christchurch, New Zealand; and P.O. Box 89, Christchurch, New Zealand.

1883. Mackenzie, Thomas Brown, Messrs. J. Copeland and Co., Pulteney Street Engine Works, Glasgow; and 342 Duke Street, Glasgow.

1883. Malan, Ernest de Mérindol, Howden.

1868. Mappin, Frank, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.

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1883. Marrack, Philip, R.N., H.M.S. "Himalaya"; and Burraton, Saltash, R.S.O., Cornwall.
1882. Martindale, Warine Ben Hay, Dharwar, Deccan, India; and 21 Kensington Gardens Square, London, W.
1881. Milles, Robert Sydney, St. Margaret's, Staplehurst.
1867. Mitchell, John, Swaithe Hall, Barnsley.
1868. Moor, William, Jun., Cross Lanes, Hetton-le-Hole, near Fence Houses.
1885. Mudie, Charles, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.
1872. Napier, Robert Twentyman, Messrs. Napier Shanks and Bell, Yoker, near Glasgow.
1878. Newall, John Walker, Arnold Road, Bow, London, E.
1882. Noble, Saxton William Armstrong, Sir W. G. Armstrong Mitchell and Co. Elswick Works, Newcastle-on-Tyne.
1881. Norris, Moraston Ormerod, Assistant Engineer, Public Works Department, Madras: 31 Castle Street, Hereford.
1883. O'Connor, John Frederick, 16 Exchange Place, New York.
1883. Osborn, William Fawcett, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.
1881. Oswell, William St. John, Broom Hill, Orpington, S. O., Kent.
1883. Palchoudhuri, Bipradas, Moheshgunj Factory, Krishnugher, Bengal.
1883. Peck, Walter, Greymouth, Nelson, New Zealand.
1884. Philipson, William, Messrs. Atkinson and Philipson, 27 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]
1883. Pigott, Arthur Walter, Rathmines, Dublin.
1884. Reynolds, Thomas Blair, 5 Great George Street, Westminster, S.W.
1885. Ripley, Philip Edward, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich.
1881. Rogers, Philip Powys, Assistant Engineer, Wardha Coal State Railway, Warora, Central Provinces, India; care of Messrs. Grindlay Groom and Co., Bombay, India.
1884. Roux, Paul Louis, 138 Rue Amelot, Paris.
1882. Sanchez, Juan Emilio, 31 Rivadavia, Buenos Aires, Argentine Republic: (or care of Mateo Clark, 4 St. Mary Axe, London, E.C.)
1882. Scott, Charles Herbert, Bessemer Steel Works, Sheffield.
1881. Scott, Ernest, Close Works, Newcastle-on-Tyne. [*Esco, Newcastle-on-Tyne.* 432.]
1883. Simpson, Charles Liddell, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.
1884. Sollory, George Henry, Messrs. H. Sollory and Son, 2 Mount Street, Nottingham.
1883. Spooner, Henry John, 309 Regent Street, London, W.

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1884. Streatfeild, Mervyn Armytage, Chested, Chiddingstone, Eden-Bridge, Kent.
1883. Swale, Gerald, Ingfield Hall, Settle.
1885. Tangye, John Henry, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham.
1884. Taylor, Joseph, 1 Somerville Terrace, Ennersdale Road, Lewisham, London, S.E.
1884. Taylor, Maurice, Ateliers des Forges et Chantiers de la Méditerranée, Marseille, France.
1884. Templeton, Edwin Arthur Slade, care of John C. Fell, 1 Queen Victoria Street, London, E.C.
1878. Waddington, John, Jun., 35 King William Street, London Bridge, London, E.C.
1882. Wailes, George Herbert, St. Andrews, Watford, Herts.
1885. Wakefield, William Marsden, Messrs. M. Powis Bale and Co., Appold Street, Finsbury, London, E.C.
1884. Walker, Matthew, Cavendish Crescent North, The Park, Nottingham.
1884. Walker, Ralph Teasdale, Messrs. Easton and Anderson, Erith Iron Works, Erith, S.O., Kent; and Kaliemaas, Alleyne Park, West Dulwich, London, S.E.
1883. Westmacott, Henry Armstrong, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne.
1880. Weymouth, Francis Marten, Messrs. Crompton and Co., Arc Works, Chelmsford; and Vine Cottage, Baddow Road, Chelmsford.
1879. Wood, Edward Walter Naylor, Resident Engineer, Great Indian Peninsula Railway, Sholapur, India.
1880. Wood, John Mackworth, Engineer's Department, New River Water Works, Clerkenwell, London, E.C.
1882. Woollcombe, Reginald, Assistant Engineer, Public Works Department, India; care of Messrs. King King and Co., Bombay.
1885. Wray, Charles Drinkwater, Guildford House, Rozel Road, Clapham, London, S.W.
1884. Yokoi, Saku, Dai Gaku, Tokio, Japan.

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THE INSTITUTION OF MECHANICAL ENGINEERS.

Memorandum of Association.

August 1878.

1st. The name of the Association is "The Institution of Mechanical Engineers."

2nd. The Registered Office of the Association will be situate in England.

3rd. The objects for which the Association is established are:—

(a.) To promote the science and practice of Mechanical Engineering and all branches of mechanical construction, and to give an impulse to inventions likely to be useful to the Members of the Institution and to the community at large.

(b.) To enable Mechanical Engineers to meet and to correspond, and to facilitate the interchange of ideas respecting improvements in the various branches of mechanical science, and the publication and communication of information on such subjects.

(c.) To acquire and dispose of property for the purposes aforesaid.

(d.) To do all other things incidental or conducive to the attainment of the above objects or any of them.

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4th. The income and property of the Association, from whatever source derived, shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly, by way of dividend, bonus, or otherwise howsoever, by way of profit to the persons who at any time are or have been Members of the Association, or to any of them, or to any person claiming through any of them: Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any Member of the Association, or other person, in return for any services rendered to the Association, or prevent the giving of privileges to the Members of the Association in attending the meetings of the Association, or prevent the borrowing of money (under such powers as the Association and the Council thereof may possess) from any Member of the Association, at a rate of interest not greater than five per cent. per annum.

5th. The fourth paragraph of this Memorandum is a condition on which a licence is granted by the Board of Trade to the Association in pursuance of Section 23 of the Companies Act 1867. For the purpose of preventing any evasion of the terms of the said fourth paragraph, the Board of Trade may from time to time, on the application of any Member of the Association, impose further conditions, which shall be duly observed by the Association.

6th. If the Association act in contravention of the fourth paragraph of this Memorandum, or of any such further conditions, the liability of every Member of the Council shall be unlimited; and the liability of every Member of the Association who has received any such dividend, bonus, or other profit as aforesaid, shall likewise be unlimited.

7th. Every Member of the Association undertakes to contribute to the Assets of the Association in the event of the same being wound up during the time that he is a Member, or within one

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year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a Member, and of the costs, charges, and expenses for winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding Five Shillings, or in case of his liability becoming unlimited such other amount as may be required in pursuance of the last preceding paragraph of this Memorandum.

8th. If upon the winding up or dissolution of the Association there remains, after the satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the Members of the Association, but shall be given or transferred to some other Institution or Institutions having objects similar to the objects of the Association, to be determined by the Members of the Association at or before the time of dissolution; or in default thereof, by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter.

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Articles of Association.

August 1878.

INTRODUCTION.

Whereas an Association (hereinafter called "the existing Institution") called "The Institution of Mechanical Engineers" has long existed for objects similar to the objects expressed in the Memorandum of Association of the Association (hereinafter called "the Institution") to which these Articles apply, and the existing Institution consists of Members, Graduates, Associates, and Honorary Life Members, and is possessed of books, drawings, and property used for the objects aforesaid;

And whereas the Institution is formed for furthering and extending the objects of the existing Institution, by a registered Association, under the Companies Acts 1862 and 1867; and terms used in these Articles are intended to have the same respective meanings as they have when used in those Acts, and words implying the singular number are intended to include the plural number, and *vice versâ*;

Now therefore it is hereby agreed as follows:—

CONSTITUTION.

1. For the purpose of registration the number of Members of the Institution is unlimited.

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MEMBERS.

2. The subscribers of the Memorandum of Association, and such other persons as shall be admitted in accordance with these Articles, and none others, shall be Members of the Institution, and be entered on the register as such.

3. Any person may become a Member of the Institution who, being a Member of the existing Institution, shall agree to transfer his membership of the existing Institution, and all rights and obligations incidental thereto, to the Institution, and to be registered as a Member of the Institution accordingly.

4. Any person may become a Member of the Institution who shall be qualified and elected as hereinafter mentioned, and shall agree to become such Member, and shall pay the entrance fee and first subscription accordingly.

5. The rights and privileges of every Member of the Institution shall be personal to himself, and shall not be transferable or transmissible by his own act or by operation of law.

QUALIFICATION AND ELECTION OF MEMBERS.

6. The qualification of Members shall be prescribed by the Bye-laws from time to time in force, as provided by the Articles.

7. The election of Members shall be conducted as prescribed by the Bye-laws from time to time in force, as provided by the Articles.

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GRADUATES, ASSOCIATES, AND HONORARY LIFE MEMBERS.

8. Any person may become a Graduate, Associate, or Honorary Life Member of the Institution, who, being already a Graduate, Associate, or Honorary Life Member of the existing Institution, shall agree to transfer his interest in the existing Institution, and all rights and obligations incidental thereto, to the Institution.

9. The Institution may admit such other persons as may be hereafter qualified and elected in that behalf as Graduates, Associates, and Honorary Life Members respectively of the Institution, and may confer upon them such privileges as shall be prescribed by the Bye-laws from time to time in force, as provided by the Articles: Provided that no Graduate, Associate, or Honorary Life Member shall be deemed to be a Member within the meaning of the Articles.

10. The qualification and mode of election of Graduates, Associates, and Honorary Life Members, shall be prescribed by the Bye-laws from time to time in force, as provided by the Articles.

ENTRANCE FEES AND SUBSCRIPTIONS.

11. The Entrance Fees and Subscriptions of Members, Graduates, and Associates, shall be prescribed by the Bye-laws from time to time in force, as provided by the Articles: Provided that no Entrance Fee shall be payable by a Member, Graduate, or Associate of the existing Institution.

EXPULSION.

12. If any Member, Graduate, or Associate shall leave his subscription in arrear for two years, and shall fail to pay such arrears within three months after a written application has been sent to him by the Secretary, his name may be struck off the list of Members, Graduates, or Associates, as the case may be, by the Council, at any time afterwards, and he shall thereupon cease to

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have any rights as a Member, Graduate, or Associate, but he shall nevertheless continue liable to pay the arrears of subscription due at the time of his name being so struck off: Provided always, that this regulation shall not be construed to compel the Council to remove any name if they shall be satisfied the same ought to be retained.

13. The Council may refuse to continue to receive the subscriptions of any person who shall have wilfully acted in contravention of the regulations of the Institution, or who shall in the opinion of the Council have been guilty of such conduct as shall have rendered him unfit to continue to belong to the Institution; and may remove his name from the list of Members, Graduates, or Associates (as the case may be), and such person shall thereupon cease to be a Member, Graduate, or Associate (as the case may be) of the Institution.

GENERAL MEETINGS.

14. The first General Meeting shall be held on such day, within four months of the registration of the Institution, as the Council shall determine. Subsequent General Meetings shall consist of the Ordinary Meetings, the Annual General Meeting, and of Special Meetings as hereinafter defined.

15. The Annual General Meeting shall take place in London in one of the first four months of every year. The Ordinary Meetings shall take place at such times and places as the Council shall determine.

16. A Special Meeting may be convened at any time by the Council, and shall be convened by them whenever a requisition signed by twenty Members of the Institution, specifying the object of the Meeting, is left with the Secretary. If for fourteen days after the delivery of such requisition a Meeting be not convened in accordance therewith, the Requisitionists or any twenty Members

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of the Institution may convene a Special Meeting in accordance with the requisition. All Special Meetings shall be held in London.

17. Seven clear days' notice of every Meeting, specifying generally the nature of any special business to be transacted at any Meeting, shall be given to every Member of the Institution, and no other special business shall be transacted at such Meeting; but the non-receipt of such notice shall not invalidate the proceedings of such Meeting. No notice of the business to be transacted (other than such ballot lists as may be requisite in case of elections) shall be required in the absence of special business.

18. Special business shall include all business for transaction at a Special Meeting, and all business for transaction at every other Meeting, with the exception of the reading and confirmation of the Minutes of the previous Meeting, the election of Members, Graduates, and Associates, and the reading and discussion of communications as prescribed by the Bye-laws, or any regulations of the Council made in accordance with the Bye-laws.

PROCEEDINGS AT GENERAL MEETINGS.

19. Twenty Members shall constitute a quorum for the purpose of a Meeting other than a Special Meeting. Thirty Members shall constitute a quorum for the purposes of a Special Meeting.

20. If within thirty minutes after the time fixed for holding the Meeting a quorum is not present, the Meeting shall be dissolved, and all matters which might, if a quorum had been present, have been done at a Meeting (other than a Special Meeting) so dissolved, may forthwith be done on behalf of the Meeting by the Council.

21. The President shall be Chairman at every Meeting, and in his absence one of the Vice-Presidents; and in the absence of all Vice-Presidents a Member of Council shall take the chair; and if

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no Member of Council be present and willing to take the chair, the Meeting shall elect a Chairman.

22. The decision of a General Meeting shall be ascertained by show of hands, unless, after the show of hands, a poll is forthwith demanded, and by a poll when a poll is thus demanded. The manner of taking a show of hands or a poll shall be in the discretion of the Chairman, and an entry in the Minutes, signed by the Chairman, shall be sufficient evidence of the decision of the General Meeting. Each Member shall have one vote and no more. In case of equality of votes the Chairman shall have a second or casting vote: Provided that this Article shall not interfere with the provisions of the Bye-laws as to election by ballot.

23. The acceptance or rejection of votes by the Chairman shall be conclusive for the purpose of the decision of the matter in respect of which the votes are tendered: Provided that the Chairman may review his decision at the same Meeting if any error be then pointed out to him.

BYE-LAWS.

24. The Bye-laws set forth in the schedule to these Articles, and such altered and additional Bye-laws as shall be added or substituted as hereinafter mentioned, shall regulate all matters by the Articles left to be prescribed by the Bye-laws, and all matters which consistently with the Articles shall be made the subject of Bye-laws. Alterations in, and additions to, the Bye-laws, may be made only by resolution of the Members at an Annual General Meeting, after notice of the proposed alteration or addition announced at the previous Ordinary Meeting, and not otherwise.

COUNCIL.

25. The Council of the Institution shall be chosen from the Members only, and shall consist of one President, six Vice-Presidents, fifteen ordinary Members of Council, and of the Past-

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Presidents; and the first Council (which shall include Past-Presidents of the existing Institution) shall be as follows:—

PRESIDENT.

John Robinson	Manchester.

PAST-PRESIDENTS.

Sir William G. Armstrong, C.B., D.C.L., LL.D., F.R.S.	Newcastle-on-Tyne.
Frederick J. Bramwell, F.R.S.	London.
Thomas Hawksley	London.
James Kennedy	Liverpool.
John Penn, F.R.S.	London.
John Ramsbottom	Manchester.
C. William Siemens, D.C.L., F.R.S.	London.
Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S.	Manchester.

VICE-PRESIDENTS.

I. Lowthian Bell, M.P., F.R.S.	Northallerton.
Charles Cochrane	Stourbridge.
Edward A. Cowper	London.
Charles P. Stewart	London.
Francis W. Webb	Crewe.
Percy G. B. Westmacott	Newcastle-on-Tyne.

COUNCIL.

Daniel Adamson	Manchester.
John Anderson, LL.D., F.R.S.E.	London.
Henry Bessemer	London.
Henry Chapman	London.
Edward Easton	London.
David Greig	Leeds.
Jeremiah Head	Middlesbrough.
Thomas R. Hetherington	Manchester.
Henry H. Laird	Birkenhead.
William Menelaus	Dowlais.
Arthur Paget	Loughborough.
John Penn, Jun.	London.
George B. Rennie	London.
William Richardson	Oldham.
John C. Wilson	Bristol.

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26. The first Council shall continue in office till the Annual General Meeting in the year 1879. The President, two Vice-Presidents, and five Members of the Council (other than Past-Presidents), shall retire at each succeeding Annual General Meeting, but shall be eligible for re-election. The Vice-Presidents and Members of Council to retire each year shall, unless the Council agree amongst themselves, be chosen from those who have been longest in office, and in cases of equal seniority shall be determined by ballot.

27. The election of a President, Vice-Presidents, and Members of the Council, to supply the place of those retiring at the Annual General Meeting, shall be conducted in such manner as shall be prescribed by the Bye-laws from time to time in force, as provided by the Articles.

28. The Council may supply any casual vacancy in the Council (including any casual vacancy in the office of President) which shall occur between one Annual General Meeting and another, and the President or Members of the Council so appointed by the Council shall retire at the succeeding Annual General Meeting. Vacancies not filled up at any such Meeting shall be deemed to be casual vacancies within the meaning of this Article.

OFFICERS.

29. The Treasurer, Secretary, and other employés of the Institution shall be appointed and removed in the manner prescribed by the Bye-laws from time to time in force, as provided by the Articles. Subject to the express provisions of the Bye-laws the officers and servants of the Institution shall be appointed and removed by the Council.

30. The powers and duties of the officers of the Institution shall (subject to any express provision in the Bye-laws) be determined by the Council.

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POWERS AND PROCEDURE OF COUNCIL.

31. The Council may regulate their own procedure, and delegate any of their powers and discretions to any one or more of their body, and may determine their own quorum: if no other number is prescribed, three Members of Council shall form a quorum.

32. The Council shall acquire the property of the existing Institution, and shall manage the property, proceedings, and affairs of the Institution, in accordance with the Bye-laws from time to time in force.

33. The Treasurer may, with the consent of the Council, invest in the name of the Institution any moneys not immediately required for the purposes of the Institution in or upon any of the following investments (that is to say):—

(A.) The Public Funds, or Government Stocks of the United Kingdom, or of any Foreign or Colonial Government guaranteed by the Government of the United Kingdom.

(B.) Real or Leasehold Securities, or in the purchase of real or leasehold properties in Great Britain or Ireland.

(C.) Debentures, Debenture Stock, or Guaranteed or Preference Stock, of any Company incorporated by special Act of Parliament, the ordinary Shareholders whereof shall at the time of such investment be in actual receipt of half-yearly or yearly dividends.

(D.) Stocks, Shares, Debentures, or Debenture Stock of any Railway, Canal, or other Company, the undertaking whereof is leased to any Railway Company at a fixed or fixed minimum rent.

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(E.) Stocks, Shares, or Debentures of any East Indian Railway or other Company, which shall receive a contribution from Her Majesty's East Indian Government of a fixed annual percentage on their capital, or be guaranteed a fixed annual dividend by the same Government.

(F.) The security of rates levied by any corporate body empowered to borrow money on the security of rates, where such borrowing has been duly authorised by Act of Parliament.

34. The Council may, with the authority of a resolution of the Members in General Meeting, borrow moneys for the purposes of the Institution on the security of the property of the Institution.

35. No act done by the Council, whether *ultra vires* or not, which shall receive the express or implied sanction of the Members of the Institution in General Meeting, shall be afterwards impeached by any Member of the Institution on any ground whatsoever, but shall be deemed to be an act of the Institution.

NOTICES.

36. A notice may be served by the Council of the Institution upon any Member, Graduate, Associate, or Honorary Life Member, either personally or by sending it through the post in a prepaid letter addressed to such Member, Graduate, Associate, or Honorary Life Member, at his registered place of abode.

37. Any notice, if served by post, shall be deemed to have been served at the time when the letter containing the same would be delivered in the ordinary course of the post, and in proving such service it shall be sufficient to prove that the letter containing the notice was properly addressed and put into the post office.

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38. No Member, Graduate, Associate, or Honorary Life Member, not having a registered address within the United Kingdom shall be entitled to any notice; and all proceedings may be had and taken without notice to such Member in the same manner as if he had had due notice.

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Bye-laws.

(*Last Revision, January* 1885.)

MEMBERSHIP.

1. Members, Graduates, Associates, and Honorary Life Members of the existing Institution, may, upon signing and forwarding to the Secretary of the Institution a claim according to Form D in the Appendix, become Members, Graduates, Associates, or Honorary Life Members respectively of the Institution without election or payment of entrance fees.

2. Candidates for admission as Members must be Engineers not under twenty-four years of age, who may be considered by the Council to be qualified for election.

3. Candidates for admission as Graduates must be Engineers holding subordinate situations and not under eighteen years of age; and they may afterwards be admitted as Members at the discretion of the Council.

4. Candidates for admission as Associates must be gentlemen not under twenty-four years of age, who from their scientific attainments or position in society may be considered eligible by the Council.

5. The Council shall have the power to nominate as Honorary Life Members gentlemen of eminent scientific acquirements, who in their opinion are eligible for that position.

6. The Members, Graduates, Associates, and Honorary Life Members shall have notice of and the privilege to attend all Meetings, but Members only shall be entitled to vote thereat.

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ENTRANCE FEES AND SUBSCRIPTIONS.

7. An Entrance Fee of £2 shall be paid by each Member, except Members of the existing Institution, who shall pay no Entrance Fee, and Graduates admitted as Members, who shall pay an Entrance Fee of £1. Each Member shall pay an Annual Subscription of £3.

8. An Entrance Fee of £1 shall be paid by each Graduate, except Graduates of the existing Institution, who shall pay no Entrance Fee. Each Graduate shall pay an Annual Subscription of £2.

9. An Entrance Fee of £2 shall be paid by each Associate, except Associates of the existing Institution, who shall pay no Entrance Fee. Each Associate shall pay an Annual Subscription of £3.

10. All Subscriptions shall be payable in advance, and shall become due on the 1st day of January in each year; and the first Subscription of Members, Graduates, and Associates, shall date from the 1st day of January in the year of their election.

ELECTION OF MEMBERS, GRADUATES, AND ASSOCIATES.

11. A recommendation for admission according to Form A in the Appendix shall be forwarded to the Secretary, and by him be laid before the next Meeting of the Council. The recommendation must be signed by not less than five Members if the application be for admission as a Member or Associate, and by three Members if it be for a Graduate.

12. All Elections shall take place by ballot, three-fifths of the votes given being necessary for election.

13. All applications for admission shall be communicated by the Secretary to the Council for their approval previous to being

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inserted in the ballot list for election, and the approved ballot list shall be signed by the President and forwarded to the Members. The ballot list shall specify the name, occupation, and address of the Candidates, and also by whom proposed and seconded. The lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

14. The Elections shall take place at the General Meetings only.

15. When the proposed Candidate is elected, the Secretary shall give him notice thereof according to Form B; but his name shall not be added to the list of Members, Graduates, or Associates of the Institution until he shall have paid his Entrance Fee and first Annual Subscription, and signed the Form C in the Appendix.

16. In case of non-election, no mention thereof shall be made in the Minutes, nor any notice given to the unsuccessful Candidate.

17. A Graduate or Associate desirous of being transferred to the class of Members shall forward to the Secretary a recommendation according to Form E in the Appendix, signed by not less than five Members, which shall be laid before the next meeting of Council for their approval. On their approval being given, the Secretary shall notify the same to the Candidate according to Form F if an Associate, and according to Form G if a Graduate; but his name shall not be added to the list of Members until he shall have signed the Form H, and, if a Graduate, shall have paid £1 additional entrance fee, and £1 additional subscription for the current year.

ELECTION OF PRESIDENT, VICE-PRESIDENTS, AND MEMBERS OF COUNCIL.

18. Candidates shall be put in nomination at the General Meeting preceding the Annual General Meeting, when the Council are to present a list of their retiring Members who offer themselves for re-election; any Member shall then be entitled to add to the

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list of Candidates. The ballot list of the proposed names shall be forwarded to the Members. The ballot lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

APPOINTMENT AND DUTIES OF OFFICERS.

19. The Treasurer shall be a Banker, and shall hold the uninvested funds of the Institution, except the moneys in the hands of the Secretary for current expenses. He shall be appointed by the Members at a General or Special Meeting, and shall hold office at the pleasure of the Council.

20. The Secretary of the Institution shall be appointed as and when a vacancy occurs by the Members at a General or Special Meeting, and shall be removable by the Council upon six months' notice from any day. The Secretary shall give the same notice. The Secretary shall devote the whole of his time to the work of the Institution, and shall not engage in any other business or profession.

21. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all meetings of the Institution, and of the Council, and of Committees; to take minutes of the proceedings of such meetings; to read the minutes of the preceding meetings, and all communications that he may be ordered to read; to superintend the publication of such papers as the Council may direct; to have the charge of the library; to direct the collection of the subscriptions, and the preparation of the account of expenditure of the funds; and to present all accounts to the Council for inspection and approval. He shall also engage (subject to the approval of the Council) and be responsible for all persons employed under him, and set them their portions of work and duties. He shall conduct the ordinary business of the Institution, in accordance with the Articles and Bye-laws and the directions of the President and Council; and shall refer to the

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President in any matters of difficulty or importance, requiring immediate decision.

MISCELLANEOUS.

22. All Papers shall be submitted to the Council for approval, and after their approval shall be read by the Secretary at the General Meetings, or by the Author with the consent of the Council.

23. All books, drawings, communications, &c., shall be accessible to the Members of the Institution at all reasonable times.

24. All communications to the Meetings shall be the property of the Institution, and be published only by the authority of the Council.

25. None of the property of the Institution—books, drawings, &c.—shall be taken out of the premises of the Institution without the consent of the Council.

26. All donations to the Institution shall be enumerated in the Annual Report of the Council presented to the Annual General Meeting.

27. The General Meetings shall be conducted as far as practicable in the following order :—

1st. The Chair to be taken at such hour as the Council may direct from time to time.

2nd. The Minutes of the previous Meeting to be read by the Secretary, and, after being approved as correct, to be signed by the Chairman.

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3rd. The Ballot Lists, previously opened by the Council, to be presented to the Meeting, and the new Members, Graduates, and Associates elected to be announced.

4th. Papers approved by the Council to be read by the Secretary, or, with the consent of the Council, by the Author.

28. Each Member shall have the privilege of introducing one friend to any of the Meetings; but, during such portion of any meeting as may be devoted to any business connected with the management of the Institution, visitors shall be requested by the Chairman to withdraw, if any Member asks that this shall be done.

29. Every Member, Graduate, Associate, or Visitor, shall write his name and residence in a book to be kept for the purpose, on entering each Meeting.

30. The President shall ex officio be Member of all Committees of Council.

31. Seven clear days' notice at least shall be given of every meeting of the Council. Such notice shall specify generally the business to be transacted by the meeting. No business involving the expenditure of the funds of the Institution (except by way of payment of current salaries and accounts) shall be transacted at any Council meeting unless specified in the notice convening the meeting.

32. The Council shall present the yearly accounts to the Members at the Annual General Meeting, after being audited by a professional accountant, who shall be appointed annually by the Members at a General or a Special Meeting, at a remuneration to be then fixed by the Members.

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33. In the case of Members, Associates, or Graduates, elected in the last three months of any year, the first subscription shall cover both the year of election and the succeeding year.

34. No Proceedings or Ballot Lists shall be sent to Members, Associates, or Graduates, who are in arrear with their subscriptions more than twelve months.

35. Any Member wishing to have a copy of the Papers sent to him for consideration beforehand can do so by sending in his name once in each year to the Secretary; and a copy of all Papers shall then be forwarded to him as early as possible prior to the date of the Meeting at which they are intended to be read.

36. At any Meeting of the Institution any Member shall be at liberty to re-open the discussion upon any Paper which has been read or discussed at the preceding Meeting; provided that he signifies his intention to the Secretary at least one month previously to the Meeting, and that the Council decide to include it in the notice of the Meeting as part of the business to be transacted.

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APPENDIX.

FORM A.

Mr. being not under twenty-four years of age, and desirous of admission into the Institution of Mechanical Engineers, we the undersigned proposer and seconder from our personal knowledge, and we the three other signers from trustworthy information, propose and recommend him as a proper person to become a thereof.

Witness our hands, this day of

Members.

FORM B.

Sir,—I have to inform you that on the you were elected a of the Institution of Mechanical Engineers. In conformity with the rules, your election cannot be confirmed until the enclosed form be returned to me with your signature, and until your Entrance Fee and first Annual Subscription be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the election will become void.

I am, Sir,

Your obedient servant,

Secretary.

FORM C.

I, the undersigned, being elected a of the Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they are now formed or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

FORM D.

As a of the Institution of Mechanical Engineers, I claim to become a of the Association incorporated under the same name.

Please register me as a

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FORM E.

Mr. being of the required age, and desirous of being transferred into the class of Members of the Institution, we, the undersigned, from our personal knowledge, recommend him as a proper person to become a Member of the Institution of Mechanical Engineers.

FORM F.

SIR,—I have to inform you that the Council have approved of your being transferred to the class of Members of the Institution of Mechanical Engineers. In conformity with the rules, your transference cannot be confirmed until the enclosed form be returned to me with your signature. If this be not received within two months from the present date, the transference will become void.

I am, Sir,

Your obedient servant,

Secretary.

FORM G.

SIR,—I have to inform you that the Council have approved of your being transferred to the class of Members of the Institution of Mechanical Engineers. In conformity with the rules, your transference cannot be confirmed until the enclosed form be returned to me with your signature, and until your additional Entrance Fee (£1) and additional Annual Subscription (£1) be paid for the current year. If these be not received within two months from the present date, the transference will become void.

I am, Sir,

Your obedient servant,

Secretary.

FORM H.

I, the undersigned, having been transferred to the class of Members of the Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they now exist, or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

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Institution of Mechanical Engineers.

PROCEEDINGS.

January 1885.

The Thirty-eighth Annual General Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Thursday, 29th January 1885, at Half-past Seven o'clock p.m.; I. Lowthian Bell, Esq., F.R.S., Retiring President, in the chair, succeeded by Jeremiah Head, Esq., President elected at the Meeting.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following twenty-nine candidates were found to be duly elected:—

MEMBERS.

Frederick Henry Anson,	London.
Tom Birkett Barker,	Birmingham.
Henry Francis Boughton,	Barnsley.
Benjamin J. Brearley,	St. Helens.
Walter Chapman Burder,	Loughborough.
Charles Alfred Adolph Capito,	London.
John Chapman,	Eton.
Richard Kendall Evans,	Nottingham.
William Henry Fowler,	Manchester.
Joseph Harrison,	London.
Thomas James Haughton,	London.
Robert Anderson Hill,	London.

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THOMAS HINDMARSH,	London.
CHARLES HOPKINSON,	Manchester.
RICHARD HUNT,	London.
HENRY JOHN CUBITT KEYMER,	Gorleston.
ROBERT LOW,	Woolwich.
CHARLES THOMAS MILLIS,	London.
ROBERT ROBSON NEWLOVE,	Nottingham.
CHARLES DAVID PHILLIPS,	Newport, Mon.
HENRY PARNHAM PHILLIPS,	Insein, Burma.
JOHN RYAN, D.Sc.,	Nottingham.
JAMES SCORGIE,	Poona, India.

GRADUATES.

EWART CHARLES AMOS,	London.
LESLIE CLARKE,	London.
LORENZO WILLIAM CROSTA,	Nottingham.
JOHN MACPHERSON GRANT,	Newcastle-on-Tyne.
JOHN HERBERT HOLROYD,	Manchester.
THOMAS LAIDLER,	London.

The following Annual Report of the Council was then read:—

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ANNUAL REPORT OF THE COUNCIL.

1885.

The Council have the pleasure of presenting to the Members, on this occasion of the Thirty-eighth Anniversary of the Institution, the following Annual Report for the past year.

The total number of names of all classes on the roll of the Institution at the end of last year 1884 was 1554, as compared with 1440 at the end of the previous year. The increase of 114 has arisen as follows:—there were added to the register during the year 163 names of all classes; there were lost from the register by deceases 25 names, and by resignation or removal 24 names.

The following two Associates and six Graduates have been transferred by the Council in the course of the year to the class of Members:—

JAMES STUART, M.P., ...	Associate	Cambridge.
ALEXANDER JAMES WALLIS TAYLER,	do.	London.
JOHN EDWARD COMPTON-BRACEBRIDGE,	Graduate	London.
NORMAN HART, ...	do.	London.
NORMAN JOSEPH LOCKYER, ...	do.	Manchester.
RAYNES LAUDER MCLAREN, ...	do.	London.
THOMAS HENRY PEARSON, ...	do.	Wigan.
ROBERT EDWARD PHILLIPS, ...	do.	London.

The following twenty-one Deceases of Members of the Institution have occurred during the past year:—

THOMAS BALDWIN, ...	Manchester.
JOHN BORRIE, ...	Stockton-on-Tees.
WILLIAM BRAGGE, ...	Birmingham.
MASSEY BROMLEY, ...	London.
WALTER RALEIGH BROWNE, ...	London.
JOHN BUTLER, ...	Stanningley.

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CHARLES EDWARD DARBY,	Wrexham.
DAVID HARDMAN FLETCHER,	Manchester.
HENRY ALLASON FLETCHER,	Whitehaven.
RICHARD GARRETT,	Leiston.
JOHN JABEZ GEACH (deceased 1883),	Bath.
WILLIAM ARTHUR HARRISON,	Manchester.
EDWARD EDWARDS HEWETT,	Sheffield.
HENRY JAMES JACKSON,	London.
JAMES KERR,	London.
THOMAS KIRKWOOD,	Hong Kong.
JOHN LANCASTER,	Rugby.
ROBERT LÜTHY,	Bolton.
GEORGE PEAKER,	Kirkee.
GEORGE RICHARDSON,	Oldham.
JOHN PROCTOR WOODHEAD,	Manchester.

The following seven gentlemen have ceased to be Members of the Institution during the past year:—

JAMES ANDERSON,	Mouram, Russia.
THOMAS JOSEPH DAWSON,	Fence Houses.
ROBERT ELSDON,	London.
WILLIAM THOMPSON,	London.
ARTHUR HENRY WALKER (Graduate),	Bridgend.
EDWARD JOHN COWLING WELCH,	London.
ISAIAS WHITE,	Seville.

In addition there have been seventeen Resignations of membership during the year.

The Accounts for the year 1884, having been passed by the Finance Committee, and having been audited by Messrs. Robert A. McLean and Co., chartered accountants, are now submitted to the Members (*see* Appendix I, pp. 10–13). It will be seen that the receipts for the year have been £5094 14*s.* 11*d.*, while the expenditure has been £3968 6*s.* 5*d.*, leaving a balance of receipts over expenditure of £1126 8*s.* 6*d.* A Balance Sheet is also appended, showing the financial position of the Institution at the end of the year to be satisfactory. The total investments and other assets amounted to £16,180 3*s.* 9*d.*, and the liabilities being *nil* the same

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amount constituted the capital of the Institution at the end of the year. The greater part of the capital, as will be seen, is invested in Four per cent. Railway Debenture Stocks, registered in the name of the Institution. The Council have since directed a further investment of £1350.

With regard to Research, the Council are indebted to Sir Frederick Abel for the completion of his promised report on Steel, which will be read to the present Meeting. The report by Professor Kennedy upon his latest experiments on Riveted Joints has also been received in readiness for circulation among the Members. The Members will agree with the Council that their cordial thanks are due to Sir Frederick Abel and Professor Kennedy, for the large amount of time and thought they have alike bestowed upon the preparation and carrying out of their respective experimental investigations, as well as upon their valuable reports; and also to Mr. Tomlinson for the continuance of the facilities which he has so obligingly afforded in connection with the Friction experiments. The second report upon the experiments conducted by the Committee on Friction will be read to the present Meeting.

The Donations to the Library of the Institution during the past year, for which the Council have the pleasure of expressing their thanks to the Donors, are enumerated in Appendix II, pp. 14–21. Donations of books, original pamphlets, or reports, and particularly of records of practical experiments or researches, are invited by the Council for enlarging and improving the Library.

The General Meetings in 1884 were the Annual General Meeting and the Spring Meeting, each of two days and held in London; the Summer Meeting held in Cardiff; and the Autumn Meeting held in Nottingham. There was also a Special Meeting in London in the spring for election of Secretary. The Papers read and discussed at the six sittings devoted to the purpose, and published in the Proceedings, were the following:—

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Report on Friction Experiments; by Mr. Beauchamp Tower. (Adjourned Discussion.)

On the Physical Condition of Iron and Steel; by Professor D. E. Hughes, F.R.S.

On the Consumption of Fuel in Locomotives; by M. Georges Marié.

On Portable Railways; by M. Paul Decauville.

On the Moscrop Engine Recorder, and the Knowles Supplementary Governor; by Mr. Michael Longridge.

Description of the Automatic and Exhaust-Steam Injector; by Mr. A. Slater Savill.

Description of the Apparatus used for Testing Current-Meters, at the Admiralty Works at Torquay for experimenting on models of ships; by Mr. Robert Gordon.

On recent extensions of Dock Accommodation and Coal-Shipping Machinery at the Bute Docks, Cardiff; by Mr. John McConnochie.

Description of the new Locomotive Running Shed of the Taff Vale Railway at Cathays, Cardiff; by Mr. Charles H. Riches.

Description of the Francke "Tina" or Vat Process for the Amalgamation of Silver Ores; by Mr. Edgar P. Rathbone.

On the use of Petroleum Refuse as Fuel in Locomotive Engines; by Mr. Thomas Urquhart.

On the Causes and Remedies of Corrosion in Marine Boilers; by Mr. J. Harry Hallett.

On the Mineral Wagons of South Wales; by Mr. Alfred Slater.

On the application of Electro-Magnets to the working of Railway Signals and Points; by Mr. Illius A. Timmis.

The attendances at the Meetings were as follows:—at the Annual General Meeting 239 Members and 39 Visitors; at the Spring Meeting 106 Members and 45 Visitors; at the Summer Meeting 241 Members and 115 Visitors; and at the Autumn Meeting 86 Members and 49 Visitors. At the Special Meeting, of Members only, the attendance was 215.

The Summer Meeting held in Cardiff afforded the Members an opportunity of realising the rapid extension which had taken place of the coal and iron industries and of shipbuilding and engineering establishments during the ten years which had elapsed since the former Meeting of the Institution in that locality in 1874. On the present occasion the proceedings were opened with an Address

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from the President, which presented in the clearest light to the consideration of mechanical engineers the causes contributing to many of the difficulties latterly encountered in carrying on engineering enterprises successfully, particularly such as are mainly devoted to the manufacture of iron and steel. The Address was followed by a second valuable Paper from Mr. John McConnochie, which traced the extensions that have taken place during the last ten years in the dock accommodation and coal-shipping machinery at Cardiff. Both Address and Paper alike received the best possible practical commentary in the very excellent opportunities so liberally afforded to the Members for visiting a number of the principal iron and engineering works and collieries of the district, as well as the docks and coal-shipping appliances both at Cardiff and at Newport. To so highly successful and enjoyable a Summer Meeting as this was rendered by the untiring exertions of the local Members and their friends, no better ending could have been devised than the interesting visit on the last day of the week to the Severn Tunnel Works, of which a large number of the Members stayed to take advantage.

The Autumn Meeting, held in Nottingham on the initiative of the principal local Members, was through their activity made the occasion of invitations to visit engineering and manufacturing works in the town and neighbourhood, of which the Members attending the Meeting were kindly afforded the opportunity of availing themselves both on the day of the Meeting and on the following day.

The Council have the pleasure of announcing that they have received a cordial invitation to hold this year's Summer Meeting of the Institution in the city of Lincoln. The principals of the important engineering industries there, and also at Gainsborough, Grantham, Newark, and Frodingham, have offered to do all in their power to render the visit agreeable and interesting to the Members. The Council have gladly accepted the invitation, and in concert with the Local Committee will proceed to make all necessary arrangements. The Meeting will commence on Tuesday, 4th August.

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In accordance with the Rules of the Institution, the President, two Vice-Presidents, and five Members of Council in rotation, go out of office this day. The result of the ballot for the election of the Council for the present year will be reported to the Meeting. At the last Meeting the circumstances were explained under which, for the first time during the last twenty-four years, the President will not on this occasion continue in office for a second year. While sharing the regret of the Council at the decision which Mr. Bell has thus found it necessary to take, the Members will all concur with them in the cordial hope that the step which deprives the Institution of the advantage of his second year's presidency may, by relieving him of the responsibilities attaching to the post, conduce to the preservation of his health and strength through many coming years of enjoyment to himself and of benefit to the community at large.

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APPENDIX I.

EXPENDITURE AND RECEIPTS.

BALANCE SHEET.

1884.

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APPENDIX I.

Dr. ACCOUNT OF EXPENDITURE AND RECEIPTS

Expenditure.	£	s.	d.	£	s.	d.
To Printing and Engraving Proceedings of 1884	761	0	7			
„ Reprinting former Proceedings	258	7	0			
	1019	7	7			
Less Authors' Copies of Papers, repaid	39	10	9	979	16	10
„ Stationery, Binding, and General Printing				213	12	9
„ Rent				550	0	0
„ Salaries and Wages				1,314	0	5
„ Coals, Firewood, and Gas				38	14	4
„ Fittings and Repairs, and new Furniture				93	10	1
„ Postages				245	6	4
„ Insurance				5	2	3
„ Travelling Expenses				48	5	10
„ Petty Expenses				72	0	10
„ Meeting Expenses—						
Printing	117	1	5			
Reporting	58	0	9			
Diagrams, Screen, &c.	4	1	4			
Travelling and Incidental Expenses	106	10	1	285	13	7
„ Research				66	8	2
„ Books purchased				5	0	0
„ Drawings of Watt Models				0	15	0
Total Expenditure in 1884				3,968	6	5
Balance, being excess of Receipts over Expenditure, carried down				1,126	8	6
				£5,094	14	11

Cash Balance at this date				1,854	5	4
				£1,854	5	4

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APPENDIX I.

FOR THE YEAR ENDING 31ST DECEMBER 1884. *Cr.*

Receipts.

	£	s.	d.	£	s.	d.
By Entrance Fees—						
134 *New Members at* £2	268	0	0			
6 *New Associates at* £2	12	0	0			
18 *New Graduates at* £1	18	0	0			
6 *Graduates transferred to Members at* £1	6	0	0	304	0	0
„ Subscriptions for 1884—						
1264 *Members at* £3	3,792	0	0			
35 *Associates at* £3	105	0	0			
92 *Graduates at* £2	184	0	0			
6 *Graduates transferred to Members at* £1	6	0	0	4,087	0	0
„ Subscriptions in arrear—						
43 *Members at* £3	129	0	0			
1 *Associate at* £3	3	0	0			
5 *Graduates at* £2	10	0	0			
1 *Member, instalment*	0	11	5	142	11	5
„ Subscriptions in advance—						
15 *Members at* £3	45	0	0			
1 *Graduate at* £2	2	0	0	47	0	0
„ Donation				1	14	10
„ Interest—						
From Investments	412	12	4			
From Bank	35	19	4	448	11	8
„ Reports of Proceedings—						
Extra Copies sold				63	17	0
				£5,094	14	11

By Balance brought down	1,126	8	6
Cash Balance 31st December 1883	727	16	10
	£1,854	5	4

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Dr. **BALANCE SHEET**

	£	s.	d.
Capital of the Institution at this date	16,180	8	9
	£16,180	8	9

(*Signed*) THOMAS R. CRAMPTON,
GEORGE B. RENNIE,
R. PRICE-WILLIAMS,
JOSEPH TOMLINSON, JUN., } *Finance Committee.*

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AS AT 31ST DECEMBER 1884. *Cr.*

	£	s.	d.	£	s.	d.
By Cash—*In Union Bank, on Deposit*	900	0	0			
„ „ „ *on Current account* . .	454	5	4			
In Imperial Bank	500	0	0	1,854	5	4
„ Investments—						
£						
3,178 *London & N. W. Ry.* 4% *Debenture Stock*						
2,200 *North Eastern* „ „ „ „						
2,466 *Midland* „ „ „ „						
1,800 *Great Western* „ „ „ „						
891 *Metropolitan* „ „ „ „						
10,535 . . . . . *cost*				10,617	1	4
Note—The Market Value of these investments at 31st Dec. 1884 was about £12,500.						
„ Subscriptions in Arrear				289	0	0
„ Office Furniture and Fittings				350	0	0
„ Library and Proceedings				2,669	17	1
„ Drawings, Engravings, Models, Specimens, and Sculpture .				400	0	0
				£16,180	3	9

Audited and Certified by

ROBERT A. McLEAN & Co., Chartered Accountants,
1 Queen Victoria Street, London, E.C.

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APPENDIX II.

LIST OF DONATIONS TO LIBRARY.

Hydraulic Machinery, by Henry Adams; from the author.

Joints in Woodwork, by Henry Adams; from the author.

Designing Wrought and Cast Iron Structures, Part I, by Henry Adams; from the author.

Notes on Mechanical Engineering, by Henry Adams; from the author.

Report on the Westphalian Mining School at Bochum for 1882–83; from the Director.

Plans and Sections, Thames Improvement, Ferries and Road Communications East of London Bridge; from Mr. R. J. H. Saunders.

Annual Examination (1868) of the Thomason Civil Engineering College; from Mr. Druitt Halpin.

Eisen und Stahl auf der Welt-Ausstellung in Paris im Jahre 1878, by Anton Ritter von Kerpely; from Mr. Druitt Halpin.

Utilisation des Eaux des Égoûts de la Ville de Paris; from Mr. Druitt Halpin.

Histoire du Fer dans le pays de Namur, by M. Berchem; from Mr. Druitt Halpin.

Charbons Belges en 1869, by Max Goebel; from Mr. Druitt Halpin.

City and Guilds of London Institute, Examination List; from Mr. Philip Magnus.

Domestic Electric Lighting, by A. Levy; from the author.

Marine Boiler Construction, Corrosion, and Preservation, by John A. Rowe; from the author.

Expansive Winding Engines, by F. Timmermans; from the author.

Steel and Iron (Manual of Technology), by W. H. Greenwood; from the author.

Principia Philosophiæ, by Sir Isaac Newton; from Mr. H. J. Spooner.

Report of Experiments with Whitworth 9-inch Breech-loading Gun; from Sir Joseph Whitworth.

Bequest of 120 *Vols. from the late Mr. Charles Greaves.*

The Builder, Vol. XXI to Vol. XXXVI (1863-1878).

Nature, Vol. I to Vol. XXVI (1869-1882).

Royal Society Philosophical Transactions, 1861–1874, 30 vols.

Geological Society Quarterly Journal, Vol. I to Vol. XXXVII (1845–1881).

Annual Reports of the Aëronautical Society of Great Britain, 1867–1876.

Report on American Coals, by W. R. Johnson.

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Donation of 66 Vols. from Lady Siemens.

Oeuvres de Gauthey, publiés par M. Navier, 3 vols.

Record of the Progress of Modern Engineering, by William Humber, 3 vols.

Handbuch der Maschinen Kunde, by F. K. H. Wiebe, 2 vols.

Die Patentgesetzgebung, by Dr. R. Klostermann.

Wochenschrift des Österreichischen Ingenieur- und Architekten-Vereines, Vols. I–VI.

Zeitschrift des Österreichischen Ingenieur- und Architekten-Vereines, 5 vols.

Brief Sketches of the State of Wisconsin.

History &c. of the United States.

Report on the Geology of the Lake Superior Land District, Parts I and II, by J. W. Foster and J. D. Whitney, (with Maps).

Geology of Tennessee, by James M. Safford.

Coal Regions of America, by James Macfarlane.

Annual Reports of the Geological Survey of Indiana, 1869–1878, by E. T. Cox, 9 vols. (with Maps).

Reports of the Geological Survey of Missouri, 3 vols., 1855–1871, 1872, 1873–1874.

Pennsylvania Steel Company's Catalogue.

Descriptive Catalogue of the Economic Minerals of Canada.

General Account of the Commonwealth of Kentucky.

Geological Survey of California, 1860–1864.

Natural History of New York, Geology, 4 vols.

Report of a Geological Survey of Wisconsin, Iowa, and Minnesota, by D. D. Owen, 2 vols.

Preliminary Experiments on the Mechanical and other Properties of Steel, made or collected by a Committee of Civil Engineers.

Second Geological Survey of Pennsylvania, 1874, 9 vols.

Mineral Statistics of Michigan, 1880.

Pittsburgh and Allegheny in the Centennial Year, by George H. Thurston, 2 vols.

Keystone Bridge Company's Illustrated Album, Descriptive Catalogue of Wrought-Iron Bridges.

Geological Survey of New Jersey, 1880.

Mines and Mineral Lands of Nova Scotia, by Edwin Gilpin, Jun.

The Coal Trade, by F. E. Saward.

Hydraulic Buffers, by Colonel H. Clerk, R.A., F.R.S.

Presidential Address to the Manchester Association of Employers, Foremen and Draughtsmen, by Thomas Ashbury; from the author.

Manchester Ship Canal, Description of the Project; from the Provisional Committee.

Emploi de l'Acier dans les Constructions Navales, Civiles, et Mécaniques, by S. Périssé; from the author.

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Across Chryse, by Archibald R. Colquhoun; from the author.

Notes on subjects connected with Works in the Irrawaddy Circle, British Burmah, with records of experiments on the Double Float and Woltmann Meter Current Measurements, by Robert Gordon; from the author.

Classified List and Distribution Return of Establishment, Indian Public Works Department, to 31 Dec. 1883; from the Registrar.

Catalogue of Gauges &c.; from Messrs. Schäffer and Budenberg.

Lubrication, by J. Veitch Wilson; from the Manchester Association of Employers, Foremen and Draughtsmen.

Blow-holes in Steel Ingots and Castings, by W. Annable; from the Manchester Association of Employers, Foremen and Draughtsmen.

Chapman's system of Obtaining Water from Artesian Wells, by T. Baldwin; from the Manchester Association of Employers, Foremen and Draughtsmen.

On the Recovery of the Bye-Products of Coke Manufacture, by Joseph Nasmith; from the Manchester Association of Employers, Foremen and Draughtsmen.

Engraving of the late Sir William Siemens; from Mr. E. Meyerstein.

Notes on the Construction of Ordnance; from the Chief of Ordnance Office, Washington, U.S.

Household Boiler Explosions, by William Ingham; from the author.

Access to Liverpool, with suggested improvements, by H. C. Baggallay; from Mr. R. R. W. Williams.

Ports Maritimes de la France (with 15 Maps); from the Minister of Public Works.

Practical Applications of Electricity, lectures at the Institution of Civil Engineers; from the Institution.

Return on Continuous Brakes; from the Board of Trade.

Strains in Ironwork, by Henry Adams; from the author.

Modern Progress in Mine Engineering, by Henry Bramall; from the author.

Traction Electrique, by Emile Reynier; from Mr. Henry Chapman.

Prix de Revient des Machines en France, en Angleterre, en Allemagne, by S. Périssé; from Mr. Henry Chapman.

British Iron Trade Report, 1883; from Mr. J. S. Jeans.

Munro and Jamieson's Pocket-Book of Electrical Rules and Tables; from Messrs. Charles Griffin and Co.

Liverpool Free Public Library Catalogue; from the Library.

Reports of the U.S. Chief of Ordnance; from the Ordnance Committee Office, Washington.

Stone-Working Machinery, by M. Powis Bale; from the author.

Steam and Machinery Management, by M. Powis Bale; from the author.

Injector Hydrant for Fire Extinction, by J. H. Greathead; from the author.

Classified List and Distribution Return of Establishment, Indian Public Works Department, to 30 June 1884; from the Registrar.

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Engine Capacity (Russian); from Mr. Thomas Urquhart.
Memoir of Sir William Siemens; from the Institution of Civil Engineers.
Heating Buildings by Steam from a central source, by J. H. Bartlett; from the author.
Military Small-Arms and Ammunition, by Lieut.-Col. H. Bond, R.A.; from the author.
Report on the present state of the Navigation of the River Mersey (1883), by Vice-Admiral T. A. B. Spratt, C.B., F.R.S.; from the author.
Adcock's Engineers' Pocket-Book for 1883; from the proprietor.
General outlines of Education in Japan, by S. Tegima; from the author.
Contract drawings and specifications of Gold Creek Reservoir Outlet for Brisbane Water Works; from Mr. James B. Henderson.
Calendar of the Imperial College of Engineering, Tokio, Japan; from the College.
Principles of the Manufacture of Iron and Steel, by I. Lowthian Bell, F.R.S.; from the author.
Board of Trade Reports on Boiler Explosions; from the Board of Trade.
Boiler Explosions Act, 1882; Board of Trade Reports, &c.; from the Manchester Steam Users' Association.
Engravings and Photographs of Winding, Stationary, and Forge Engines; from M. A. de Quillacq.
Depreciation of Factories and their Valuation, by Ewing Matheson; from the author.
Sewage Disposal, by Henry Robinson; from the author.
Forth Bridge, by Benjamin Baker; from the author.
Illustrated Catalogue of Steam Engines and Machinery; from Messrs. Marshall Sons and Co.
Description of the Porter-Allen Steam Engine, by Charles T. Porter; from the author.
Report of Royal Technical High School, Berlin, on opening new building; from the Rector.
London Water Supply, by Colonel Sir Francis Bolton; from the author.
Roller Milling Facts; from Mr. Henry Simon.
Patent and Copyright Laws, by A. V. Newton; from the author.

Reports of the Academy of Sciences, France; from the Academy.
Reports of the Royal Academy of Sciences, Belgium; from the Academy.
Reports of the Royal Institute of Engineers, Holland; from the Institute.
Annales des Ponts et Chaussées, Paris; from the Directors.
Proceedings of the French Institution of Civil Engineers; from the Institution.
Journal of the French Society for the Encouragement of National Industry; from the Society.

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Report of the French Association for the Advancement of Science; from the Association.

Journal of the Marseilles Scientific and Industrial Society; from the Society.

Proceedings of the Engineers' and Architects' Society of Canton Vaud; from the Society.

Proceedings of the Engineers' and Architects' Society of Austria; from the Society.

Proceedings of the Architects' and Engineers' Society of Hanover; from the Society.

Proceedings of the Engineers' and Architects' Society of Prague; from the Society.

Proceedings of the Industrial Society of St. Quentin; from the Society.

Proceedings of the Industrial Society of Mulhouse; from the Society.

Proceedings of the Industrial Society of the North of France; from the Society.

Proceedings of the Saxon Society of Engineers and Architects; from the Society.

Proceedings of the German Society of Engineers; from the Society.

Proceedings of the Swedish Society of Engineers; from the Society.

Journal of the Norwegian Technical Society; from the Society.

Journal of the Franklin Institute; from the Institute.

Transactions of the American Society of Civil Engineers; from the Society.

Transactions of the American Society of Mechanical Engineers; from the Society.

Transactions of the American Institute of Mining Engineers; from the Institute.

School of Mines Quarterly, Columbia College, New York; from the College.

Report of the Smithsonian Institution; from the Institution.

Report of the Master Car-Builders' Association, New York; from the Association.

Proceedings of the American Railway Master-Mechanics' Association; from the Association.

Proceedings of the United States Naval Institute; from the Institute.

Report of the United States Geological Survey; from the Director.

United States Patent Office Gazette; from the Office.

Professional Papers on Indian Engineering; from the Thomason College.

Proceedings and Journal of the Asiatic Society of Bengal; from the Society.

Report of the Sassoon Mechanics' Institute, Bombay; from the Institute.

Proceedings of the Institution of Civil Engineers; from the Institution.

Journal of the Iron and Steel Institute; from the Institute.

Transactions of the Society of Engineers; from the Society.

Journal of the Society of Telegraph-Engineers and Electricians; from the Society.

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Transactions of the Institution of Civil Engineers of Ireland; from the Institution.
Transactions of the North of England Institute of Mining and Mechanical Engineers; from the Institute.
Proceedings of the South Wales Institute of Engineers; from the Institute.
Transactions of the Institution of Engineers and Shipbuilders in Scotland; from the Institution.
Proceedings of the Chesterfield and Derbyshire Institute of Mining, Civil, and Mechanical Engineers; from the Institute.
Transactions of the Midland Institute of Mining, Civil, and Mechanical Engineers; from the Institute.
Proceedings of the Cleveland Institution of Engineers; from the Institution.
Transactions of the West of Scotland Mining Institute; from the Institute.
Proceedings of the Royal Society of London; from the Society.
Proceedings of the Royal Society of Edinburgh; from the Society.
Proceedings of the Royal Institution; from the Institution.
Transactions of the Institution of Surveyors; from the Institution.
Journal of the Royal United Service Institution; from the Institution.
Professional Papers of the Royal Engineers Institute; from the Institute.
Proceedings of the Royal Artillery Institution; from the Institution.
Journal of the Royal Agricultural Society of England; from the Society.
Journal of the Statistical Society; from the Society.
Report of the British Association for the Advancement of Science; from the Association.
Report of the Royal Cornwall Polytechnic Society; from the Society.
Transactions of the Institution of Naval Architects; from the Institution.
Transactions of the Royal Institute of British Architects; from the Institute.
Transactions of the Gas Institute; from the Institute.
Proceedings of the Physical Society of London; from the Society.
Proceedings of the Literary and Philosophical Society of Manchester; from the Society.
Report of the Manchester Geological Society; from the Society.
Journal of the Royal Scottish Society of Arts; from the Society.
Proceedings of the Philosophical Society of Glasgow; from the Society.
Transactions and Proceedings of the Royal Irish Academy; from the Academy.
Journal of the Liverpool Polytechnic Society; from the Society.
Journal of the Society of Arts; from the Society.
Journal of the Society of Chemical Industry; from the Society.
Transactions of the Institute of Patent Agents; from the Institute.
Reports of the Manchester Steam Users' Association; from Mr. Lavington E. Fletcher.
Reports of the Midland Steam Boiler Inspection and Assurance Co.; from Mr. Edward B. Marten.

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Records of Boiler Explosions; from Mr. Edward B. Marten.
Report of the National Boiler Insurance Company; from Mr. Henry Hiller.
Report of the Engine, Boiler, and Employers' Liability Insurance Company; from Mr. Michael Longridge.
Report of the Manchester Association of Employers, Foremen and Draughtsmen; from the Association.
Catalogue of the Liverpool Free Public Library; from the Committee.

Revue générale des Chemins de fer; from the Directors.
Bruxelles Port-de-Mer; from M. Gobert.
Stahl und Eisen; from the Editor.
Der Civil-ingenieur; from the Editor.
Glaser's Annalen; from the Editor.
Giornale del Genio Civile; from the Editor.
The Railroad Gazette; from the Editor.
The Scientific American; from the Editor.
The American Engineer; from the Editor.
The American Manufacturer; from the Editor.
The Sanitary Engineer; from the Editor.
The Engineering and Mining Journal; from the Editor.
The Engineer; from the Editor.
Engineering; from the Editor.
The Railway Engineer; from the Editor.
The Railway Record; from the Editor.
The Marine Engineer; from the Editor.
Sanitary Engineering; from the Editor.
The Foreman Engineer and Draughtsman; from the Editor.
The Building and Engineering Times; from the Editor.
The Electrical Review; from the Editor.
The Electrical Engineer; from the Editor.
Iron; from the Editor.
The Iron and Coal Trades Review; from the Editor.
Ryland's Iron Trade Circular; from the Editor.
The Ironmonger; from the Editor.
The Mechanical World; from the Editor.
The Mining Journal; from the Editor.
The Colliery Guardian; from the Editor.
The Machinery Market; from the Editor.
The Builder; from the Editor.
The Contract Journal; from the Editor.
The Gas and Water Review; from the Editor.
The Steamship; from the Editor.

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The Shipping World; from the Editor.
The Fireman; from the Editor.
The Illustrated Science Monthly; from the Editor.

The PRESIDENT said there was little calling for remark from himself in the Annual Report of the Council, of which he was sure the Members would cordially approve. In reading accounts of meetings of great industrial establishments throughout the country it was found that apologies had frequently to be made for the altered circumstances of their position. With this Institution however that was fortunately not the case. Financially, which after all was the best test of the sound position of any society, the Institution was in a very excellent position. There were some statements in the Report, for which of course no responsibility would be attached to himself; and amongst them was the very kind and flattering manner in which his humble efforts in the discharge of his duty as President had been recognised. He need scarcely say that it was a subject of very deep regret to himself that the state of his health of late had been such as to render it—he did not say imprudent on his own part so far as regarded his own convenience—but undesirable that he should continue to hold the office of President. There were questions of infinitely greater importance than his own convenience and his own health. He referred especially to the position which he conceived the President of a great Institution like this ought to hold amongst the members. On the last occasion of their meeting at Nottingham, he was unable, from circumstances which had been alluded to in the Report, to attend. He did not then think it right, and he was still of the same opinion, that the President of a great body like this should be placed in a position in which there was any uncertainty with regard to his power of attending the meetings; and under these circumstances he had felt it his bounden duty to decline the honour of continuing their President for the coming year. If there could be any circumstance which reconciled him to this very painful step, it was found in the reflection that in his

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successor, Mr. Jeremiah Head, the Institution would have a President who would be fully equal to the occasion. With these few prefatory remarks he begged to move the adoption of the Report just read.

The motion was unanimously agreed to.

The PRESIDENT announced that the Ballot Lists for the election of Officers had been opened by a committee of the Council, and the following were found to be elected for the present year:—

PRESIDENT.

JEREMIAH HEAD, ...	Middlesbrough.

VICE-PRESIDENTS.

DANIEL ADAMSON, ...	Manchester.
GEORGE B. RENNIE, ...	London.

MEMBERS OF COUNCIL.

WILLIAM ANDERSON, ...	London.
E. HAMER CARBUTT, M.P., . . .	London.
FRANCIS C. MARSHALL, . . .	Newcastle-on-Tyne.
E. WINDSOR RICHARDS, . . .	Middlesbrough.
T. HURRY RICHES, ...	Cardiff.

The chair was then taken by Mr. JEREMIAH HEAD, President elect.

Mr. JOHN RAMSBOTTOM was sure he was only expressing the feeling of the meeting when he said that he personally regretted such circumstances should have arisen as to prevent their worthy Past-President from continuing in office for the second year. He was sure they would all have been delighted if he had felt that he would be doing himself justice in retaining that position. But while expressing this view he should be the last to wish Mr. Bell to do any violence to himself in that respect: and all would feel that

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he was only doing himself an act of justice, however much they might have desired a different state of things. It was satisfactory to know that his successor was in every respect worthy to follow in his steps. He begged to move, "That the best thanks of the Members be given to their Past-President, Mr. Bell, for his conduct during the past year."

Mr. F. C. MARSHALL had very great pleasure in seconding the vote of thanks to their Past-President. It had fallen to his lot to have something to do with Mr. Bell during the last months of his presidency; and he knew from his personal intercourse with him that it was a matter of great regret to him, while it was also a matter of absolute necessity, that he should retire from the position of President. That was the very strong feeling on the part of his family and his many friends in the north of England. He was sure that all fully endorsed the sentiments so well expressed by their Past-President, Mr. Ramsbottom, to which also effect had been given in the Report just read of the Council; and all deeply regretted that their esteemed Past-President, Mr. Bell, could not continue in the presidency for a second year. In the loss of Mr. Bell's services however it was some consolation to them that he was succeeded by a gentleman from his own neighbourhood, who had to a large extent imbibed his spirit, and who he could state from his own personal experience as a north countryman had all the true genius of engineering about him, having been educated in the birthplace of the locomotive. He was sure that in their new President, Mr. Head, they had a very able successor to the highly esteemed and eminent scientist who had just retired from the presidency. He had very great pleasure in seconding the vote of thanks to their Past-President, Mr. Bell.

The motion was unanimously agreed to.

Mr. I. LOWTHIAN BELL said he was very greatly obliged for the highly flattering manner in which the members had thanked him for the way in which he had been able to discharge the duties of a

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somewhat onerous office. If he could not flatter himself that he was entitled to this warm expression of their feeling, at least he could assure the meeting that he had done the best he could during the year he had had the honour to serve them. He desired to return his very cordial thanks to his colleagues on the Council for their invariable support to him during his year of office; and not less would he wish to tender to the members generally his very hearty thanks for the manner in which they had been willing and kind enough to overlook any deficiencies of which he might have been guilty. Although leaving the highly honourable post of President, a position to which he should look back in future years as one of the greatest honours that had been accorded to him, he should not cease on that account to take the warmest interest in the prosperity of the Institution, which he hoped would continue in its career of usefulness.

The PRESIDENT said he should be of a very much more callous temperament than he was, if he did not feel very deeply the high honour that had been done him in placing him in the chair; and he should have the gift of language in much greater perfection than he had, if he could adequately express his feelings on this occasion. He was perfectly aware of the great value of the Institution, and the necessity of maintaining and forwarding its interests. Next to the Institution of Civil Engineers, to whose kindness and hospitality they owed the fact that they were met in that room, he believed the Institution of Mechanical Engineers was the most ancient engineering institution in this country. It was the second wealthiest; it had the second largest number of members, and the second largest income, and it was doing most excellent work. It had had a long line of Presidents of great eminence, beginning with George Stephenson, the father of railways, and ending with Isaac Lowthian Bell. He did not know what he himself was, or what he had done, to deserve being even at the tail end of such a list as that of their Past-Presidents. He assured the members that it was with very great diffidence that he had accepted the post. If he could have postponed it or shrunk from it altogether,

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he should certainly have been glad to do so; but he had accepted it on the solicitation and pressure of his colleagues on the Council, and having done so he should deem it to be his duty to stick to it as long as he was able, and to forward the interests of the Institution in every way in his power. He had now only to thank Mr. Bell and those gentlemen who had out of their feeling of kindness spoken so handsomely of him, and the members generally for so warmly and kindly endorsing their remarks.

He now called upon Mr. Robinson to propose the first of the motions of which he had given notice for this meeting.

Mr. CHARLES HAWKSLEY moved that, while matters were being discussed relating to the internal management of the affairs of the Institution, visitors should be asked to withdraw until the general business of the Institution was commenced.

Mr. PETER D. BENNETT seconded the motion.

Mr. GEORGE D. HUGHES proposed as an amendment that visitors should be allowed to remain.

Mr. JOHN PRICE seconded the amendment, which was supported by Mr. I. LOWTHIAN BELL, and on being put to the Meeting was carried.

Mr. JOHN ROBINSON proposed the first motion of which he had given notice, as follows:—

That Bye-Law 20 be expunged, and the following words substituted for it:—"The Secretary of the Institution shall be appointed, as and when a vacancy occurs, by the Council; and shall be removable by them by a six months' notice from any day. The Secretary shall give the same length of notice. The Secretary shall devote the whole of his time to the work of the Institution, and shall not engage in any other business or occupation except such as shall be of a purely literary character."

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Mr. I. LOWTHIAN BELL seconded the motion, which was supported by Mr. WILLIAM BOYD, Mr. CHARLES COCHRANE, Mr. THOMAS R. CRAMPTON, Mr. THOMAS R. HETHERINGTON, Mr. JOHN R. RAVENHILL, Mr. EDWARD REYNOLDS, and Mr. HENRY SHIELD; and was opposed by Mr. DANIEL ADAMSON, Mr. JOHN P. FEARFIELD, Mr. J. MCFARLANE GRAY, Mr. GEORGE D. HUGHES, Mr. ARTHUR PAGET, and Mr. JOHN C. WILSON.

A proposal by Mr. JOHN PHILLIPS, seconded by Mr. CHARLES HAWKSLEY, and supported by Mr. E. WINDSOR RICHARDS, for the postponement of the motion, was negatived.

On being put to the Meeting, the motion was lost by eighty-two votes against seventy-seven.

At Ten o'clock the Meeting was adjourned till the following evening. The attendance was 196 Members and 44 Visitors.

The ADJOURNED MEETING of the Institution was held at the Institution of Civil Engineers, London, on Friday, 30th January 1885, at Half-past Seven o'clock p.m.; JEREMIAH HEAD, Esq., President, in the chair.

The PRESIDENT announced that the following Officers had been appointed by the Council in accordance with Article 28, for supplying the vacancies occurring as the result of the election which had taken place at yesterday's Meeting:—

VICE-PRESIDENT.

WILLIAM ANDERSON, ...	London.

MEMBERS OF COUNCIL.

BENJAMIN A. DOBSON, . . .	Bolton.
ALEXANDER B. W. KENNEDY, . .	London.

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The Council for the present year would therefore be as follows:—

PRESIDENT.

JEREMIAH HEAD, ...	Middlesbrough.

PAST-PRESIDENTS.

SIR WILLIAM G. ARMSTRONG, C.B., D.C.L., LL.D., F.R.S., . . .	Newcastle-on-Tyne.
I. LOWTHIAN BELL, F.R.S., . .	Middlesbrough.
SIR FREDERICK J. BRAMWELL, F.R.S., .	London.
THOMAS HAWKSLEY, F.R.S., . .	London.
JAMES KENNEDY, ...	Liverpool.
JOHN RAMSBOTTOM, ...	Alderley Edge.
JOHN ROBINSON, ...	Manchester.
PERCY G. B. WESTMACOTT, . .	Newcastle-on-Tyne.
SIR JOSEPH WHITWORTH, BART., D.C.L., LL.D., F.R.S., . . .	Manchester.

VICE-PRESIDENTS.

DANIEL ADAMSON, ...	Manchester.
WILLIAM ANDERSON, ...	London.
CHARLES COCHRANE, ...	Stourbridge.
THOMAS R. CRAMPTON, . . .	London.
RICHARD PEACOCK, ...	Manchester.
GEORGE B. RENNIE, ...	London.

MEMBERS OF COUNCIL.

WILLIAM BOYD, ...	Newcastle-on-Tyne.
E. HAMER CARBUTT, M.P., . .	London.
BENJAMIN A. DOBSON, . . .	Bolton.
DAVID GREIG, ...	Leeds.
SAMUEL W. JOHNSON, . . .	Derby.
ALEXANDER B. W. KENNEDY, . .	London.
J. HAWTHORN KITSON, . . .	Leeds.
FRANCIS C. MARSHALL, . . .	Newcastle-on-Tyne.
ARTHUR PAGET, ...	Loughborough.

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R. PRICE-WILLIAMS, ...	London.
SIR JAMES RAMSDEN, . . .	Barrow-in-Furness.
E. WINDSOR RICHARDS, . . .	Middlesbrough.
T. HURRY RICHES, ...	Cardiff.
JOSEPH TOMLINSON, JUN., . .	London.
RALPH H. TWEDDELL, . . .	London.

Mr. JOHN ROBINSON, with the consent of the Meeting, withdrew the second of the three motions of which he had given notice for this Meeting; and proposed the third motion standing in his name, as follows:—

That the following words be added to Bye-Law 32 after the word *accountant*:—"who shall be appointed annually by the Members at a General or a Special Meeting, at a remuneration to be then fixed by the Members."

Mr. ARTHUR PAGET seconded the motion, which was carried unanimously.

The PRESIDENT, in calling upon Mr. George D. Hughes to propose the motion of which he had given notice for three alterations in Form A for the proposal of candidates desirous of joining the Institution, said that, if Mr. Hughes would accept the interpolation of the word *other* between the words *three* and *signers* in the third alteration, simply for the purpose of making the wording a little more clear, the Council were then entirely in favour of the proposed amendments in the appendix to the Bye-Laws. Form A, being the form of proposal for candidates desirous of joining the Institution as Members or Associates, would then read as follows, the three proposed alterations being shown in italics:—"Mr. . . . . being *not under twenty-four years of age*, and desirous of admission into the Institution of Mechanical Engineers, we the undersigned *proposer and seconder* from our personal knowledge, *and we the three other signers from trustworthy information*, propose and recommend him as a proper person to become a . . . . . thereof."

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Mr. GEORGE D. HUGHES said he had great pleasure in accepting the addition of the word *other* as suggested by the President, and in proposing his motion for the three alterations in Form A in the appendix to the Bye-Laws, so as to make it read as just given.

Mr. CHARLES COCHRANE seconded the motion, which was carried unanimously.

The following Reports were read and discussed:—

Final Report on Experiments bearing upon the question of the Condition in which Carbon exists in Steel; by Sir FREDERICK A. ABEL, C.B., D.C.L., F.R.S., Honorary Life Member.

Second Report of the Research Committee on Friction.

A Paper was read on recent improvements in Wood-Cutting Machinery, by Mr. George Richards, of Manchester; and the discussion was adjourned to the next Meeting.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated. The attendance was 109 Members and 33 Visitors.

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RESEARCH COMMITTEE ON THE HARDENING, ETC., OF STEEL.

FINAL REPORT ON EXPERIMENTS BEARING UPON THE QUESTION OF THE CONDITION IN WHICH CARBON EXISTS IN STEEL.

BY SIR FREDERICK ABEL, C.B., D.C.L., F.R.S.,
HON. MEM. INSTS. C.E. AND M.E., PAST-PRES. C.S., &c.

In the Report which was submitted to the Institution in January 1883, on experiments carried out with very thin discs of steel, it was shown that the results obtained appeared to confirm the correctness of the conclusion based upon the earlier experiments, that the carbon in cold-rolled steel exists in the form of a definite iron carbide, approximating to the formula Fe_3C or to a multiple of that formula, and capable of resisting the oxidising effect of an agent which exerts a rapid solvent action upon the metal through which this carbide is distributed.

It was stated that Mr. Paget had been so good as to provide several series of discs of steel, some of which had been hardened, while others had been annealed under different conditions there specified; these discs, which were 2·5 inches in diameter and 0·01 inch thick, were in the first instance examined in the hope that definite information might have been obtained in respect to the extent to which the proportion of total carbon in thin pieces of steel might undergo modification during the processes of annealing and hardening, as usually practised.

The process by which the samples of steel were examined has been described in detail in the Report of 1883. After the examination of some of a series of unnumbered discs as received from cold rolling, described as being prepared from one and the same

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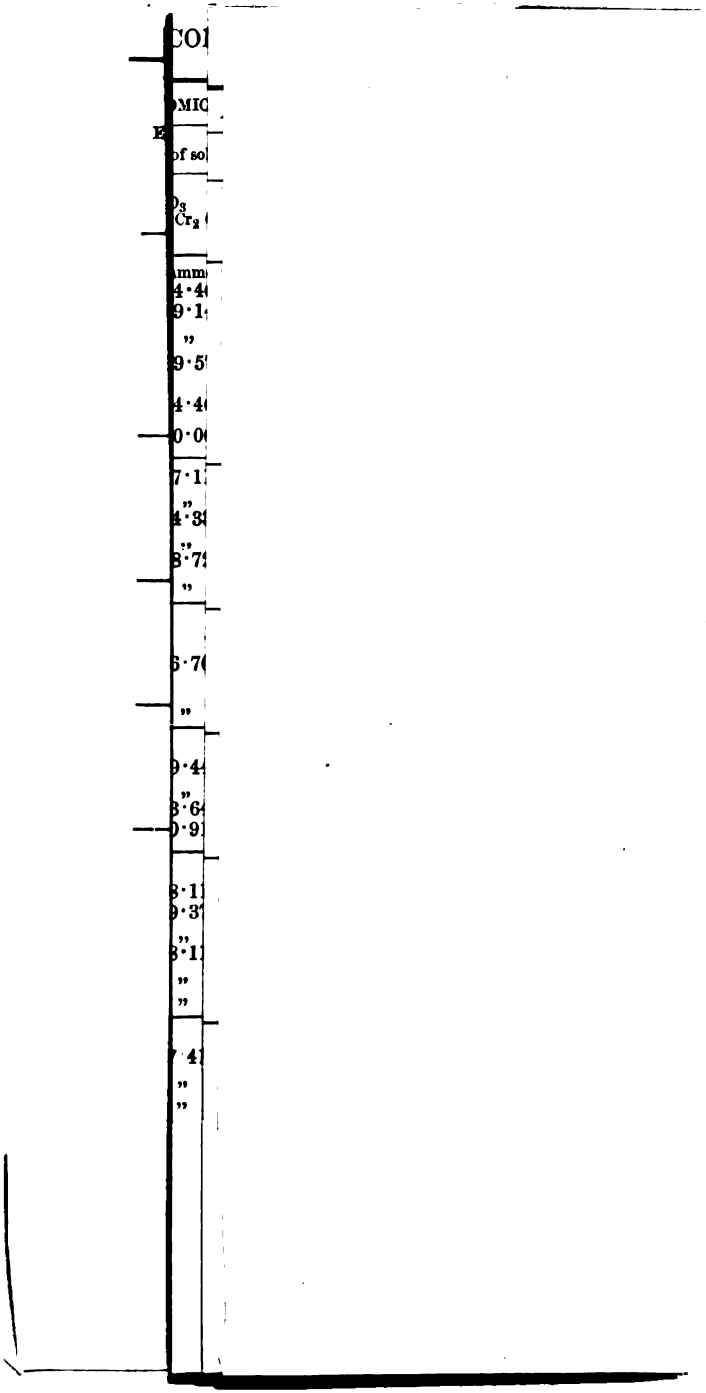

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lot of metal as that used in the preparation of the annealed and hardened discs, the carbon-determinations in the latter were proceeded with; but, after a considerable number of results had been obtained, the singularity of some of the numbers made it seem probable that there was variation in the amount of total carbon in the cold-rolled discs, and therefore also in the original discs used in the production of the differently treated specimens, which should have been uniform in composition. On returning to the cold-rolled discs, and analysing the whole, or the majority of them, it was found that variations, in some instances considerable, existed in the amount of total carbon in these. This circumstance unfortunately much diminishes the value of the results furnished by these series of discs; but, as some points of interest remain, the numbers obtained are given.

SERIES A.

"As received from cold rolling"—three discs, not numbered, contained respectively total carbon 1·066%; 1·215%; 1·061%.

"Three discs annealed in one lot," between two black wrought-iron plates placed in a wrought-iron box inside a cast-iron box, the space between the boxes packed with burnt soot, kept at a red heat about an hour, and left about 36 hours to cool (arranged between the two plates in the order as they are numbered). The total carbon in disc No. 3 was 1·161%; disc No. 2 contained 1·018%.

"Three discs made red-hot between two black cast-iron plates and hardened in water." Not numbered. One disc contained 1·235% of carbon.

"Three discs made red-hot between two black cast-iron plates and hardened between planed cast-iron plates." Not numbered. One disc contained 1·130% of carbon.

SERIES F.

"Six discs as received from cold rolling." Not numbered. Five discs examined were found to contain 1·076, 1·083, 1·225, 1·222, 1·073% of carbon.

"Six discs annealed by placing them between two blocks of fire-clay, these being placed in a cast-iron box and the space between

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them packed with calcined magnesia." The discs were arranged between the blocks in the order as numbered.

A disc with no visible figure, but which must have been No. 2 or No. 6 of this lot, contained 1·058%; disc No. 3 contained 1·276%; disc No. 4 contained 1·088% of carbon.

SERIES B and C.

Fourteen Discs described as all having been cut from the same strip.

Series B.—"Seven annealed in one lot between two wrought-iron plates planed and cleaned; in other respects the same as Series A." Arranged between the two plates in order as numbered. Disc No. 1 (next the wrought-iron plate) contained 0·821%; disc No. 4 (the middle disc) contained 0·882% of carbon.

Series C.—"Seven annealed in one lot between two cast-iron plates planed and cleaned; in other respects the same as Series A." Arranged in order as numbered. Disc 14 (next the cast-iron plate) contained 1·152% of carbon.

If all the discs were really from the same lot of steel, and on this point Mr. Paget's statement was positive, it would almost seem as if the sheet had been rolled from an ingot with a nucleus richer in carbon than the exterior portion.

In Series B a loss of carbon, due to annealing between wrought-iron plates, may be inferred with great probability: an effect already indicated by the results described in the Report of January 1883.

In Series A it seems probable that both series of the discs annealed between wrought-iron plates, which have been analysed, had fallen about 0·05% carbon; namely from 1·215% in the richer cold-rolled discs to 1·161% in the corresponding annealed specimens, and from about 1·064% to 1·018%. But this cannot be inferred with certainty, on account of the diversity in composition exhibited by the cold-rolled discs.

The employment of fire-clay blocks and calcined magnesia-packing in the annealing of the discs in Series F was suggested as a substitute for the wrought-iron plates and soot, both of which, with very thin pieces of steel, might give rise to a change in the amount of carbon. From the varying percentage of carbon in the cold-rolled

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discs of Series F, one cannot be certain with which of them the annealed discs should be compared; but those containing 1·058% and 1·088% of carbon had probably been derived from cold-rolled discs poorest in carbon, such as those containing 1·076 and 1·083% of carbon respectively. The annealed disc containing 1·276% of carbon had probably been derived from a richer disc, such as those containing 1·225% or 1·222%; or it may have been derived from a specimen still richer in carbon. The use of fire-clay plates and calcined magnesia might be worthy of a more careful trial, with provision for the absorption of the atmospheric oxygen in the heating box, otherwise than by using soot.

Before giving the details of work done in continuation of that already reported on, I take this first opportunity of noticing some results obtained by Dr. F. C. G. Müller, who called my attention to them in June 1883. They are contained in a paper on the "German Bessemer Process," which appeared in the "Zeitschrift des Vereines deutscher Ingenieure," XXII. 385, year 1878. In this paper he describes residues of undissolved carbide of iron ("amorphous iron") which, like Karsten, he obtained by the action of dilute acids on steel.

Dr. Müller treated Bessemer steel in the cold with dilute sulphuric acid (one of acid to five of water), little more than the calculated quantity having been employed. The acid was allowed to act for 12 hours, the undissolved residue was then filtered off, suitably washed, and dried in a dish on the steam-bath in a current of coal-gas. In the black residue thus obtained (which Dr. Müller found to be pyrophoric) the carbon was estimated. In six preparations, he found numbers for carbon ranging from 6·01 to 7·38%, from which Dr. Müller regards his "amorphous iron" as being probably Fe_3C. In these preparations a very large quantity of the total carbon must have been converted into hydrocarbons; as, calculating from the numbers given in the five cases, only 53, 73, 41, 19, 50% of the total carbon in the steel were obtained in the amorphous iron.

In the experiments reported on to the Institution in January 1883, a mixture of bichromate of potassium and sulphuric acid was used,

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the oxidising chromic acid enabling one to work with weaker sulphuric acid without fear of uncombined metallic iron being able to resist the double attack, while the chromic acid to a large extent prevents the formation of hydrocarbons, by greatly diminishing the formation of hydrogen. In preparations with three different strengths of chromic solution, 85, 90, and 91 per cent. of the total carbon in the steel were obtained in the respective residues of carbide; results which have been confirmed by the more recent experiments, in respect of the annealed or cold-rolled steels examined. The close approach of Dr. Müller's sulphuric acid residues to the composition Fe_3C is very interesting as a testimony to the existence of such a compound, additional to that afforded by the Report of January 1883; and I gladly take this opportunity of calling attention to Dr. Müller's results, which would not have escaped me, had they appeared in a publication having greater currency among chemists.

The investigation of the main subject—the Condition in which Carbon exists in Steel—was continued by experiments similar to those described in the Report of January 1883. Those were conducted with one kind of steel in one condition; and showed that, when the steel was acted upon by a solution (bichromate of potassium solution *plus* sulphuric acid) containing more than enough of acid to dissolve its iron, together with combined oxygen which was able greatly to diminish the formation of hydrogen, about 90 per cent. of the total carbon was left in combination with iron as an insoluble iron carbide. The ratio of sulphuric acid to bichromate of potassium was kept constant, the proportion of bichromate in the solution being varied. Three experiments showed a good agreement, both in the amount of carbide left by solutions containing varying quantities of chromic acid, and in the composition of these carbides; the fourth experiment showed that there was a limit to the stability of the carbide.

In the experiments now to be considered, the result of varying the ratio of the sulphuric acid to the bichromate was first tried; and then, for the remaining solutions, one uniform ratio (equal weights) between the sulphuric acid and bichromate was maintained.

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The steel operated on and its condition were also varied. The steel used for the experiments described in the last Report had been fused; and the condition in which several cold-rollings, with annealing between the rollings, would leave it, would not be very definite, but nearer to that of annealed than of hardened steel. In the present experiments the behaviour of an unfused cemented steel was tried, first as received from cold-rolling, then as annealed and hardened, and in the condition of straw- and blue-temper. Other annealed and hardened plates from fused steel were also examined; and finally experiments were made with a series of straw- and blue-tempered discs from fused steel, which had been kept at the corresponding temperatures for a short and for a long time.

The numbers obtained are put together in the accompanying Table (facing page 48), and to a great extent explain themselves; but a short description of the mode of experimenting and of the material used may be desirable.

Method of Experimenting.— The experiments were conducted very similarly to those of the last Report, except that the supports of platinum gauze on which the steel then rested were now replaced by perforated glass vessels, to meet a point raised by Professor Hughes as to a possible objection to the employment of platinum in the acid solution in which the steel was immersed. These perforated glass vessels were supported immersed in the upper part of the acidulated chromic solution, contained in a capacious beaker. The weighed portion of steel (previously cleaned with emery, then with cold ether, and wiped) was dipped into the solution and taken out and stroked while moist with the finger until action began, then dropped on to the glass sieve in the liquid. Solution proceeded rapidly, ferric and chromic sulphates streaming to the bottom of the beaker, and the fresh chromic solution taking the place of the reduced portion. In the case of hardened steel, solution was attended with a rather considerable evolution of hydrogen; in the case of annealed steel the evolution of gas was slight, but continuous. The solution of uncombined iron was probably in all cases complete within 24 hours; the glass sieve was rinsed into the liquid, the latter stirred up, and

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left for another 24 hours. The liquid was then decanted on to a filter, and the heavy insoluble deposit slightly washed with water by decantation; some fresh chromic solution was added to it, and they were left together, with occasional shaking round, for at least another 24 hours. The liquid was then decanted on to a filter, the deposit thoroughly washed with water by decantation, afterwards transferred to a small porcelain vessel, washed once with cold alcohol, twice with cold ether, dried in vacuo over sulphuric acid, and weighed until constant. All the liquids were passed through filters, on which a small quantity of carbide remained; the iron in this was estimated, and the amount of carbide thus ascertained was added to the main quantity. The carbide being heavy, the quantity on the filter was always quite a small proportion of the whole.

If it had been possible, the steel would have been treated with the chromic solution for one day, the liquid stirred up and left for one day, and the insoluble matter treated with fresh chromic solution for one day; in some cases however, the claims of other work protracted the total time of treatment to a week. But in all instances, if two or more kinds of steel were being compared, the comparative experiments were all started at the same time, and carried on in the same way. The uncombined iron was apparently in all cases almost wholly dissolved by the first quantity of chromic solution, the second portion showing to the eye but slight signs of reduction.

There was at first, during solution, a small rise of temperature; in all but the very first experiments, the beakers were placed in cold water during the first night.

The chromic solutions were prepared from cold saturated solutions of bichromate of potassium; they were not of one strength however; in some cases cold nights brought salt out of solution, and in the earlier solutions, which were prepared by allowing hot solutions of bichromate to cool down, it was found that more salt crystallised out than was compatible with a saturated condition of the cold solution. These variations in strength presented however no disadvantage, the yield of carbide not being directly affected by

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them. The amount of bichromate of potassium in each cold solution having been estimated, the desired quantity of pure strong sulphuric acid was added, and the acidulated solution left until the next day.

As the amount of free sulphuric acid present in the solutions affects greatly the yield of carbide, it was desirable, at least in the later experiments, to avoid the presence of unreasonably large quantities thereof. The number given in the Table under the head of "free sulphuric acid sufficient for dissolving grammes iron" was calculated on the supposition that all the bichromate was converted into chromic acid and neutral sulphate of potassium, and that all the sulphuric acid remaining was used in the conversion of iron into ferric sulphate, and in the formation of chromic sulphate from the reduced chromic acid. Thus:—

(*a*) $$K_2 Cr_2 O_7 + H_2 SO_4 = 2 Cr O_3 + K_2 SO_4 + H_2O.$$

(*b*) $$Fe_2 + 2 CrO_3 + 6 H_2SO_4 = Fe_2 (SO_4)_3 + Cr_2 (SO_4)_3 + 6 H_2O.$$

By equation *a*, 1 gramme of sulphuric acid is required for every 3 grammes of bichromate of potassium. By equation *b*, 1 gramme of iron requires 5·2537 grammes of sulphuric acid. The quantities of sulphuric acid required by *a* and *b* were combined in calculating the amount of iron which the acidulated chromic solution could dissolve.

As a matter of fact, these solutions are able to dissolve more iron than this calculated amount. This is partly due to the escape of some hydrogen, which, as it does not reduce chromic acid, causes a smaller quantity of sulphuric acid to be required for the formation of chromic sulphate; possibly also, in solutions of the strengths used, all the bichromate is not converted into chromic acid, some sulphuric acid being hence saved on equation *a*. Several of the solutions, after having dissolved all the free iron of the steel, were tested as to their power of dissolving more iron, and found still to possess solvent power.

In all the experiments, the reduced chromic solutions were clear and bright, showing no signs of the presence of basic sulphates; this fact, combined with the ability of those reduced solutions so tested to dissolve more iron, and with the slight reduction only of

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the second portion of chromic solution used, affords ample guarantee of the presence of sufficient sulphuric acid in the solutions.

The data of the four solutions used in the experiments of the Report of January 1883 are re-calculated on the basis of equations *a* and *b*, and are given at the foot of the Table.

The Analysis of the Carbide.—The carbide, after drying at ordinary atmospheric temperature over sulphuric acid in vacuo, was weighed in a porcelain boat and analysed by direct combustion in oxygen in the usual manner; the amount of oxide of copper being diminished as far as was prudent. Although the oxide was invariably heated to redness before use, the process of combustion always furnished traces of water, from other sources than from the carbide. A blank combustion was made, when the drying-tube increased in weight 0·0052 gramme, and the apparatus for absorbing carbonic acid increased only 0·0005 gramme. The above amount of water (0·0052 gramme) is deducted in the numbers, representing the amount of water, included in the Table under the head "analysis of the carbide"; although it may not be strictly accurate to deduct this quantity in all cases, it is believed that the results are brought nearer the truth by so doing.

The heating with hydrochloric acid was performed as stated in the last Report.

With the exception of one or two darker preparations, which subsequent examination showed to be partly decomposed, all the carbides obtained were grey-black heavy powders, not at all pyrophoric at ordinary temperatures.

The first experiments were made with unfused Cemented (L) Dannemora steel, which was supplied by Messrs. Wilson and Co. It was in one long strip, 0·01 inch thick, about $2\frac{3}{4}$ inches broad, more than 1 lb. in weight, and was as left by the cold rolling.

Some of the strip was used for experiments 1 to 5, then a portion was used for analysis; and another estimation of carbon was made in a second portion before cutting off the steel for experiment 7.

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The original steel contained :—total carbon, 0·941 %; silicon, 0·006 %; manganese, 0·009 %. The total carbon in the second portion was 0·913 %.

Digested with hydrochloric acid until solution of the iron, and the insoluble matter treated as usual, there was obtained of carbon unconverted into hydrocarbons (uncombined carbon?) 0·018 per 100 of steel. This should have been taken into account in the corresponding percentages given by the carbides, but to avoid complication this was not done. With this steel as received, experiments 1 to 6 were made; the numerical details of the solutions used, and of the percentages and composition of the insoluble products obtained, are given in the Table. The following are some additional particulars of these six experiments, which were made between October and December 1883.

Experiment 1.—Not specially cooled; the first portion of chromic solution was allowed to act for four days, the second portion for two days.

Experiment 2.—Not specially cooled; two days and two days respectively.

Experiment 3.—Cooled in water during the first day; do. do.

Experiment 4.—Not specially cooled; two days and three days respectively.

Experiment 5.—Not specially cooled; two days and two days respectively.

Experiment 6.—Same as experiment 5. The first portion of chromic solution used for experiment 6 was examined, after it had done its two days' work, to see if it could dissolve more iron. Two grammes more of the same steel were dissolved up (except the usual black powder) within 24 hours.

The products of experiments 2, 3, and 4, though expressed as carbide obtained, are obviously decomposed carbides; they were darker in colour, and less strongly attracted by the magnet, than the other products. The number for "percentage of total carbon in the steel obtained as carbide" is too favourable in these cases; the actual carbide is given better by the percentage of iron in these insoluble products.

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Experiments 2 and 3 show that the carbide of iron is readily decomposed by a large excess of sulphuric acid in the solutions (at any rate in presence of chromic acid), the percentage of the steel's total carbon obtained in the insoluble residue being very greatly reduced, and the residue being really a very much decomposed carbide (consisting of carbide and hydrate of carbon). Experiment 4 shows that simply diluting a chromic solution which contains an excessive quantity of sulphuric acid does not give a greatly improved result in the total obtained, but causes less decomposition of the carbide. The intermediate solution of experiment 5 has given a result intermediate between 2, 3, 4 and experiments 1 and 6; and the good results with the solutions of experiments 1 and 6 show that equal weights of bichromate and sulphuric acid can be used without appreciable decomposition of the carbide of iron. Experiment 6 shows that a large excess of such acidulated chromic solution, in respect of the steel taken, can be used without detriment to the percentage of carbon obtained as carbide.

In all the solutions used in the following experiments, equal weights of bichromate and sulphuric acid were employed.

Annealed and Hardened Steel.—Eight pieces (each weighing 7 to 8 grammes) were cut off the above strip of Cemented (L) Dannemora steel; Mr. Paget had four of these annealed in fire-clay blocks and magnesia, and four hardened between planed cast-iron plates. Two of the annealed plates were cut into halves; two halves (a half of each plate) were used for the total carbon estimations, and two halves for the solvent treatment; and similarly with two hardened plates.

The annealed steel contained 1·015 %, the hardened 0·995 % of total carbon.

Three pairs of experiments were made with these preparations; the numerical results are given as experiments 7, 8, 9, 10, 11, 12 in the Table. Experiments 7 and 8 were done in March; 9 and 10 in June; and none of those four liquids was cooled.

In experiments 7 and 8, the first portion of chromic solution was allowed to act for three days, the second portion for three days. In

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experiments 9 and 10 the first treatment was continued for three days and four days respectively.

Experiments 11 and 12 were made in November; the liquids were cooled by water during the first 15 hours, in which time the greater part of the work of solution is accomplished. The first portion of chromic solution was allowed to act for four days, the second portion for one day.

These details are given because the three pairs of experiments agree very well both in amount of carbide and in the composition of the carbide from the annealed steel, while there were considerable variations in the conditions of the experiments. The agreement in the amount of carbide obtained in experiment 7 (12·8 %), with the 12·5 % furnished by the much stronger (in chromic acid) solution of experiment 9, is of importance in connection with the experiments with tempered steel. The three small quantities of carbide from the hardened steel were strongly attracted by the magnet; there was not enough for a satisfactory analysis. The first portion of chromic liquid of experiment 7, and that of experiment 8, after they had done the work of solution, were tried with two grammes of the original cold-rolled steel to see if they were still able to dissolve iron; after a lapse of two days the steel was found in both cases to have dissolved up (except the usual amount of carbide).

Experiments 13 and 14 were made with discs of Mr. Paget's Series F, mentioned in the annealing &c. experiments in the commencement of this Report. The halves of three discs were taken for each experiment, the other halves were used for estimation of total carbon. In the case of the annealed specimens this estimation was lost; and the mean percentage of carbon in the three discs previously examined (1·140) had to be taken. The hardened halves contained 1·093 % of carbon. The experiments were made in cool weather, the liquids were not specially cooled, and in both experiments the two portions of chromic solution were allowed to act each for three days. The agreement between the numbers for carbide obtained, &c., and those furnished by the other experiments with annealed and hardened specimens is very satisfactory, but the sum of the percentages is surprisingly low; however, the important

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numbers for carbon, for water, and for carbon not converted into hydrocarbons, agree well with the numbers given by the other annealed steels. The result of the analysis made with the product from the hardened steel is satisfactory, in that it shows this product to be undecomposed carbide.

Tempered Steel.—Twelve discs of tempered steel were prepared by Mr. Paget; they were cut from the strip of Cemented (L) Dannemora steel already examined; each was 2½ inches diameter. They were hardened, and six tempered blue and six straw. The blue discs were of very even colour, the straw discs showed some blue colour on one side. The halves of three discs were used for experiment 15, and the other three halves for carbon estimation; and similarly for experiment 16. The straw contained 0·928 %, the blue 0·917 % of total carbon.

Experiments 15 and 16 were made in early summer, and the solutions were not specially cooled; the two portions of chromic solution acted for three days and four days respectively in both cases.

In the repeat experiments, Nos. 17 and 18, the weather was cooler, the solutions were cooled in water during the first night, and the time in both cases was three days and one day. Less carbide however was obtained in these experiments than in 15 and 16; it is not easy to see why, other conditions having been favourable to a contrary result. The smaller yield may have been owing to the larger amount of sulphuric acid in the solution, in consequence of the greater strength in bichromate of the original liquid; yet, as experiment 9 shows, this was not seriously injurious in the case of annealed steel. A lower yield of carbide from blue- than from straw-tempered steel was also not expected; the ratio of 1 to 2 approximately is maintained however in the pairs of experiments. It is against probability that the blue-tempered should give less than the straw-tempered; but it appears very possible that the hotter blue discs may in some way have been chilled on removal from the tempering-bath, considering the small weight and large surface of the very thin discs operated upon. These experiments

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are given principally to illustrate the results of analyses of the carbide of experiments 15 and 16; they show very slight decomposition.

Experiments 19 to 34.—Tempered steel. These experiments were made with 24 discs of Fused steel; they were 0·01 inch thick, $2\frac{7}{16}$ inches diameter, and had been cut out of one and the same strip of steel. They were tempered by Mr. Paget to straw- and blue-temper, having all been heated between red-hot cast-iron plates, and hardened between cold cast-iron plates, as usual.

Six of the discs were tempered to a straw colour by immersion in a bath of molten metal for 15 minutes, and six were also tempered to a straw colour by exposure in a hot chamber for about 6 hours; two batches of six were tempered blue by similar treatment. All the discs showed a very uniform distribution of colour. This series of discs was asked for, in the hope that they might furnish more definite results than the other specimens of tempered steel; and also to see whether the prolonged tempering, which Mr. Paget, from practical experience, believes to favour toughness and durability of temper, causes any chemical change. As usual, the halves of three discs were used for the estimation of total carbon, while the other halves were used for experiments 22 and 23. "Straw, hot chamber, 6 hours," gave 1·148%; and "blue, metal bath, 15 minutes," gave 1·120% total carbon. The steel also contained 0·161% silicon and 0·169% manganese.

Three sets of four experiments were made with this batch; in all cases the solutions were cooled in water during the first half-day's treatment. The time of action of the two portions of chromic solution was the same for each set of four experiments (about three days and three days respectively), and very nearly the same for the whole of experiments 19 to 34, except the two repeat experiments with "blue, 15 minutes" (Nos. 31 and 32), when the total time of treatment was shortened to four days.

All the solutions used for these experiments were of very nearly the same strength in chromic acid. Experiments 30 and 34 also were satisfactory as evidence that the addition of water to the solutions did not affect the yield of carbide.

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The discs were divided with a pair of hand-shears, and it was observed that, of "straw, tempered in metal bath, 15 minutes," five discs were hard and brittle, giving a jagged edge, while the sixth cut soft and with a smooth edge. All the other eighteen discs, namely those of "straw, 6 hours," and also those of "blue, 15 minutes" and "blue, 6 hours," are noted as being under the shears hard and brittle.

A separate experiment was made with a hard half-disc and with a soft half-disc of "straw, 15 minutes" (experiments 20 and 21), but the same percentage of carbide was obtained.

The analysis of the carbides from the two kinds of blue-tempered steel, and from the two kinds of straw-tempered steel, experiments 25 to 28, showed them to have very nearly the same composition, and to approximate closely to that of the carbide from annealed steel. The result of analysis of carbide from "blue, 15 minutes," experiments 31 and 32, showed that slight decomposition had taken place. There was not material enough for heating these preparations with hydrochloric acid.

The yield of carbide from "straw, 15 minutes" was well maintained, in all the experiments, at about 5·1%. The first number obtained for carbide from "straw, 6 hours" (experiment 22) was 2·52%, which is inexplicable; but higher and fairly concordant results were furnished by the other three experiments (Nos. 26, 29, and 30), the numbers being 5·30%, 5·66%, and 5·52%, and giving a mean of about 5·5%. In the case of "blue, 6 hours," the low number 4·61%, obtained in experiment 24, may be set aside, as experiments 28, 33, and 34 all gave higher and concordant results, the numbers being 6·66%, 6·60%, 6·76% respectively, and giving a mean of 6·7%. In the case of "blue, 15 minutes," all four experiments (Nos. 23, 27, 31, 32) gave low percentages—2·37%, 3·02%, 3·05%, 3·14%; the mean of the last three gave 3·1%. This result with "blue, 15 minutes" is difficult to be understood, unless it be that these discs became accidentally chilled on removal from the metal bath.

Had these tempered steels behaved like annealed steel in leaving 90% of their total carbon as a carbide of iron, containing 7% carbon, the yield of carbide would have been 14·5%.

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As regards the composition of the carbide, the analyses of carbides from the cold-rolled and annealed steel show great uniformity in composition, in those cases where the yield of carbide had been large. Where the yield of carbide was highest, the percentage of iron in the carbide is highest, and carbon and water lowest. The tempered steel, having its carbon in a state intermediate between that of hardened and of annealed steel, gives a mixed result, as regards the comparison of carbide obtained per 100 of steel with the percentage composition of that carbide. The mean composition of the carbides obtained in the best experiments is given in the following statement, which includes the mean of the three given in the Report of January 1883 :—

	Water.	Carbon.	Iron
Cold-rolled Steel. Mean of experiments 1 and 6 .	0·93%	6·92%	92·77%
Annealed Steel. Mean of experiments 7, 9, and 11	1·32	7·04	91·80
Tempered Steel. The 4 kinds of blue and straw. Mean of experiments 25, 26, 27, and 28 .	2·28	7·23	89·92
Cold-rolled Steel, January 1883. Mean of Preparations 1 to 3	2·09	7·12	90·87

Although some portion of the water (less than 0·93%) in the carbide may be there as mechanically retained moisture, there seems no doubt that the greater part of it is present as a constituent of a carbo-hydrate which is a product of decomposition of the carbide, as this increase in the proportion of water is attended by an increase of carbon and a decrease of iron. (Compare experiments 2, 3, and 5.) While the carbon not converted into hydrocarbons by heating with H Cl gives a very valuable indication of the extent of decomposition of the carbide of iron, it would not be safe in the case of the purer specimens of carbide to deduct the whole of this unhydrogenised carbon, as it is very possible that even a perfectly pure carbide might, on digestion with dilute H Cl, have a small proportion of its carbon hydrated by the water, while almost the whole was converted into hydrocarbons by combination with hydrogen. (Compare the behaviour of silicon in iron; with a weak affinity for hydrogen, it is readily converted into a hydrate of silica when the iron is treated with aqueous acid.)

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It will be seen that the averages above given of the composition of the carbides afford further support to the statement made in the last Report, that the carbide of iron, freed from excess of metallic iron, has the composition Fe_3C, or is a multiple of it. That formula requires 6·67 % of carbon and 93·33 % of iron; regarding the carbides analysed as slightly decomposed specimens of the true carbide, the best of them approach it satisfactorily in composition.

The specific gravity is added of some of the specimens of carbide, and of the steel from which they had been prepared; the amount of material in the case of the carbides did not permit a greater degree of accuracy than about one-hundredth.

Cemented (L) *Dannemora Steel.*

Specific Gravity at 60° *F.* (*Water at* 60° *F.* = 1·00).

The steel as received from cold rolling	7·75	Carbide from the cold-rolled steel . .	6·9
The steel annealed	7·67	Carbide from the annealed steel { Exp. 9 .	7·2
		{ Exp. 11 .	7·2
The steel hardened	7·64		

There remains to be mentioned one other point of importance. In estimating the total carbon in the steels, they were treated with chloride of copper, which, when properly used, thoroughly removes the iron, and leaves the carbon as a black hydrate. Differences in the appearance of this "carbon" were noted, according to the condition of the steel. Thus, in estimating the total carbon in the steels of the annealing &c. experiments, given at the beginning of this report, it was noted that the "carbon" left by the chloride of copper treatment on a disc of Series A, hardened in water, was in large pieces as though it had been a continuous plate; one of the pieces had the circular edge of the disc. The same appearance was presented by the "carbon" from a disc of Series A, hardened between planed cast-iron plates.

In the case of a disc of Series A, and one of Series F, as received from cold-rolling (the steel being annealed between the rollings), it was noted that the "carbon" was left as a fine powder. More recently, in making for this Report total carbon estimations in steel

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in different conditions, it was noted that the "carbon" was left by the chloride of copper treatment in the following conditions:—by one cold-rolled steel, in a powdery form; by two annealed steels, in powder; by one hardened steel, in plates and bulky; by another hardened steel, in large flat pieces or plates; by a straw-tempered steel, in bulky plates; by a blue-tempered steel, in bulky plates.

These observations appear entitled to consideration in any attempt to form an opinion on the general question of the condition in which carbon exists in steel, of a particular composition but in different physical conditions. They may perhaps be regarded as an indication that a further elaboration of this subject might lead to the discovery of some simple chemical treatment of specimens of steel, capable of identifying a connection between their physical characteristics and comparatively slight variations in the condition in which the carbon and possibly other normal steel-constituents exist in the metal.

Conclusions.—The results of the experimental work described in the foregoing, and in the two preceding Reports, appear to warrant the following conclusions in regard to characteristics, recognisable by chemical examination, which are exhibited by different portions of one and the same sample of steel presenting marked physical differences consequent upon their exposure to the hardening, annealing, or tempering processes.

(1.)—In annealed steel, the carbon exists entirely, or nearly so, in the form of a carbide of iron, of uniform composition (Fe_3 C or a multiple thereof), uniformly diffused through the mass of metallic iron.

(2.)—The cold-rolled samples of steel examined were closely similar in this respect to the annealed steel, doubtless because of their having been annealed between the rollings.

(3.)—In hardened steel, the sudden lowering of the temperature from a red heat appears to have the effect of preventing or arresting the separation of the carbon, as a definite carbide, from the mass of the iron in which it exists in combination; its condition in the metal being, at any rate mainly, the same as when the steel is in a fused state. The presence of a small and variable

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proportion of Fe_3C in hardened steel is probably due to the unavoidable and variable extent of imperfection, or want of suddenness, of the hardening operation; so that, in some slight and variable degree, the change due to annealing takes place prior to the fixing of the carbon by the hardening process.

(4.)—In tempered steel, the condition of the carbon is intermediate between that of hardened and of annealed steel. The maintenance of hardened steel in a moderately heated state causes a gradual separation (within the mass) of the carbide molecules, the extent of which is regulated by the degree of heating, so that the metal gradually approaches in character to the annealed condition; but, even in the best result obtained with blue-tempered steel, that approach, as indicated by the proportion of separated carbide, is not more than about half-way towards the condition of annealed steel.

(5.)—The carbide separated by chemical treatment from blue- and straw-tempered steel has the same composition as that obtained from annealed steel.

It does not appear that this enquiry can be further extended with the prospect of obtaining any additional facts—elucidating the condition of the carbon in steel exhibiting various physical characteristics—the value of which would bear any proportion to the very laborious nature of the necessary experimental work, which has to be conducted with small quantities of material on account of the necessity of carrying out the annealing, hardening, and tempering processes with very thin pieces of steel.

I believe it will be admitted that, although the data obtained have not led to the discovery of a ready chemical method of differentiating between different degrees of temper in steel (a method of examination which Professor Hughes's interesting results have almost rendered unnecessary), they have at any rate contributed to the advancement of our knowledge of the nature of steel.

In conclusion, it is my pleasing duty once more to refer in well earned terms of commendation to the skill and perseverance with which Mr. W. H. Deering has carried out the difficult and arduous experimental work involved by this investigation.

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Discussion.

The PRESIDENT said the meeting had just listened to a very valuable Report from Sir Frederick Abel; and he thought they would admit that they did not yet know all about steel. Perhaps Mr. Paget, whose name had been frequently mentioned in the Report, and who had provided the steel which had been experimented upon, would make some remarks.

Mr. ARTHUR PAGET observed that Sir Frederick Abel appeared to be a little disappointed at the seeming irregularity of some of the pieces of steel which had been cut from one and the same lot. This he regretted, but he could assure Sir Frederick Abel and the meeting that those pieces had really been cut from the same lot that he had himself received. He had got them from a steel-manufacturer in Birmingham, who had devoted a great deal of trouble and time to producing steel for him, not at all with a view to chemical analysis or experiments, but simply as excessively thin pieces of steel rolled to within a limit of 5–10,000ths of an inch for accuracy of thickness. This was done almost as a favour in regard to the very great pains taken for obtaining the desired accuracy in thickness. He believed the Birmingham maker did his best to secure that the lot sent should all be taken from the same steel; but he could readily understand that, in the many processes of rolling required to reduce the ingot to the thickness of a sheet of paper, it was possible the lots might have got mixed. He could say however that they had not been mixed at his own works, because it so happened it was the only lot of plate of this thickness that he had in the works at the time.

In regard to the other difficulty mentioned in the Report, which would stand in the way of prosecuting enquiries further, owing to the supposed necessity of dealing with such exceedingly thin pieces of steel, it seemed to him there was perhaps a little misconception, because as far as he was concerned there was no difficulty on that score; he could just as readily deal with thicker pieces in the hardening and annealing processes. But the Research Committee,

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(Mr. Arthur Paget.)
under whose auspices these experiments had been conducted, thought that the thicker the steel the greater was the danger that there might be an absolute and perceptible difference of temper between the interior of the disc and the exterior. If Sir Frederick Abel thought that any difficulty could be obviated by the use of thicker pieces of steel, he was quite prepared as far as hardening and tempering went to take any thickness that was considered better; and if there was anything he could do in helping to prosecute the enquiry further, he should be exceedingly glad to do it. He desired to express his great regret that, owing to the unavoidable change of the evening for the discussion of this Report, Professor Hughes was prevented from being present to give his opinion on the matter from a mechanical or electrical point of view. Professor Hughes had attended the meeting of the Research Committee on the previous day, and had said that, as far as he could judge, any experiments which he could conduct for the Research Committee would in the main confirm the results now arrived at by Sir Frederick Abel in the Report just read.

Mr. EDWARD REYNOLDS was sorry he was not at all prepared to enter upon the purely chemical question treated of in the Report, which, however interesting, went but a very little way towards helping engineers out of the difficulties that they practically met with—difficulties with which he knew Sir Frederick Abel was himself constantly grappling:—namely, the differences that existed, not only in different pieces of steel (which it was not easy to avoid), but in the same piece of steel. Plenty of physical reasons could be found for such differences; but he was afraid that chemical knowledge would do very little towards helping engineers out of their difficulty.

Mr. W. H. DUGARD observed that the first report of the Research Committee on Steel (Proceedings, Oct. 1881, page 693) had concluded with a memorandum of three directions in which further investigation appeared to be needed. The third of those was to ascertain whether there was any connection between Chernoff's theory and Norris's observations on the contraction and expansion of wires. He should

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like to know whether anything had been done to ascertain that, or whether it was proposed to do so in future. From what he had seen of Professor Norris's observations, these would appear more likely to lead to useful practical results. The conclusions arrived at by Professor Norris from the behaviour of steel wires were, in the first place, that so-called "kicks," or temporary contractions during the heating and expansions during the cooling of the steel wires, afforded a measure of the hardening capacity of the steel; and also that the extent and intensity of those kicks were exactly in proportion to the hardness, very hard steel or steel hardened in mercury giving the largest amount of temporary contraction or expansion, while annealed steel gave the smallest amount. The amplitude of the kicks varied in proportion to the degree of hardness imparted to the steel during the act of cooling. It had also been found chemically by Professor Norris that very hard steel would dissolve in sulphuric acid without leaving any residue whatever, while annealed steel left a residue of carbon exactly in the form of the original piece of steel, or as it were a skeleton of it, and according to the different degrees of hardness so the amount of the residue varied. This line of research he thought if pursued would be likely to afford a ready means of testing the capacity of various kinds of steel for hardening. On a previous occasion (Proceedings, April 1882, page 146) he had already had the pleasure of drawing the attention of the Institution to the paper communicated by Professor Norris to the Royal Society in 1877, and to the diagrams which Professor Norris had then allowed him to bring to London for the inspection of the Committee or of members interested in the research. If it was proposed to pursue the investigation which the Research Committee had initiated, he thought this was a direction in which it was most probable that useful information could be obtained.

With regard to the possibility mentioned by Mr. Paget, that the thin steel supplied to him might have got mixed before reaching his works, he wished to say that as the cold-rolling of steel was a branch of his business, should any further samples be required, he should be very pleased to supply them and to undertake that they should not be mixed during the cold-rolling.

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Mr. ARTHUR BARCLAY said there was no more important use for steel than the tools which were used in fashioning materials; and after they were shaped they were all tempered to the desired quality by observation of the temper-colours. Sir Frederick Abel had carried out experiments with steel which had been tempered to a variety of colours; could he say exactly what the temper-colours in steel were? Had the colour substance, or was it simply an optical effect? He also wished to know within what limits of carbon or other alloy of iron these temper-colours appeared. It seemed to him the temper-colours were dependent on at least three factors:—there was the material of the steel, there was the heat, and there was the temper which varied with the heat and with the material. With respect to the colours could Sir Frederick Abel say it would be desirable that experiments should be made to obtain complete and reliable results? In the tables found in metallurgical works and text-books, the temper-colours were sometimes referred to the melting-point of other metallic alloys. The colour varied within very narrow limits of heat, perhaps ten degrees centigrade. But those tables differed amongst themselves to the extent of fifteen and twenty degrees. Some of the newer books repeated the account of crude experiments published even as long ago as 1815; a good deal had been done since then, and he should be glad to know more about this matter.

Mr. I. LOWTHIAN BELL said that, not being a practical steel-maker, he did not feel himself competent to say much on the question; but an observation had been made by Mr. Reynolds from which he must dissent altogether. He was not prepared to say whether the paper by Sir Frederick Abel as it now stood was calculated to afford steel-makers all that help which they might wish to obtain; but when a fear was expressed that chemical knowledge would do very little to help them, he must entirely demur to any such prediction. He would congratulate the Institution on having had the advantage of listening to the Report which had been read. Anyone who had had experience in the analysis of iron or steel, with a view to draw any general deduction in the masterly way that

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Sir Frederick Abel had done, must know what an immense amount of labour and thought must have been entailed in the compilation of this Report. To himself it was a matter of very great interest indeed to hear from Sir Frederick Abel so very clear an exposition of the condition under which carbon appeared to exist in steel. Instead of steel being a kind of irregular compound, the property of hardening and of tempering seemed in point of fact to be dependent on the greater or less quantity of a definite compound of iron and carbon, dissolved as it were through the mass itself; and that compound Sir Frederick Abel had determined to be in the proportion of three equivalents of iron to one of carbon, which indicated by calculation a compound containing 6·67 per cent. of carbon. He had himself performed a good many experiments to endeavour to determine the condition of carbon in cast-iron, because, as was well known, carbon in that compound was found not only in different proportions but in two different conditions—graphitic carbon, and combined carbon; and he had ascertained that these two conditions could be changed from one to the other. If he was not mistaken, he remembered mentioning a circumstance to Sir Frederick Abel, which at the time seemed to interest him. The circumstance was that fusion was not required in order to alter the composition of the mass. On one occasion he had taken a disc of malleable iron containing a mere trace of carbon, and had its surface planed and polished; and also a similar disc in point of size and dimensions, made of cast-iron, which was also planed and polished. These two discs were then screwed together, and enveloped in a mass of molten cast-iron so as to exclude if possible all atmospheric influences. By atmospheric influences he meant the atmosphere of the furnace in which they were immersed. They were kept there for different periods from a week to four weeks; and he had found that, without there being the slightest trace of fusion, the carbon from the cast-iron had passed as it were into the disc of malleable iron. He simply mentioned this because Sir Frederick Abel's Report had spoken of experiments in which steel discs had been placed between wrought-iron plates. He wished to ask Sir Frederick Abel whether he was satisfied that a portion of the difference observed might not

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(Mr. I. Lowthian Bell.)
be due to the wrought-iron plates (between which the steel discs had been placed) having carried off from the steel a certain portion of carbon.

With regard to the irregularity of composition of steel referred to by Mr. Paget, this did not surprise him in the least. He had frequently analysed the same mass of cast-iron, and large ingots of steel; and it was exceptional to find a perfectly uniform composition in the mass. There was frequently a greater or less quantity of carbon in one part than in another, a greater or less quantity of manganese, and a greater or less quantity of silicon.

In conclusion he would remark that they were now just entering as it were on the threshold of this question, and they should hail with gratitude any contribution which the labours of scientific men might afford to them, in order that they might obtain information on which they could proceed—not in the rule-of-thumb mode which formerly had been the invariable practice, he would not say of steel-makers, but of iron-manufacturers generally,—and investigate the nature of these compounds by a diligent study of their composition and all their qualities.

Mr. ARTHUR PAGET mentioned that in connection with Sir Frederick Abel's present Report an experiment had been tried in the direction indicated by Mr. Bell, and it was rather a curious and instructive one. Seven of these thin discs had been bolted together between a cast-iron plate on the one side and a wrought-iron plate on the other side, and the whole had been kept heated to a good red heat short of fusion in the furnace for somewhere between twenty-four and thirty-six hours. On taking them out, and judging by the hardening, tempering, bending, and such practical tests, he had been satisfied as a practical engineer, not as a chemist, that there was a somewhat regular gradation in quality between the seven discs. The one nearest the cast-iron was most steely, while the one nearest the wrought-iron was least steely, and they followed a somewhat regular gradation from the first disc to the seventh. If he remembered rightly, Sir Frederick Abel's very valuable assistant, Mr. Deering, had made some experiments which confirmed this.

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Mr. I. LOWTHIAN BELL said that entirely agreed with what might be expected. His own wrought-iron plate had been in one piece, about half an inch thick. It could not melt, because it was put in the fire-place of one of the hot-air stoves supplying a blast-furnace, and where the heat was not sufficient to fuse it. On taking it out he had had a series of layers planed off it, each about 1–32nd of an inch in thickness. These were then analysed, and, as might have been expected, the portion nearest the cast-iron was much richer in carbon than the portions that followed, and at last it ended in there being no sensible increase in the quantity of carbon. At the same time the trials were made not only for carbon, but for phosphorus and silicon; and though occasionally there were slight differences, yet they were so slight that he had set them down rather to experimental error than to any real difference.

Mr. T. EDWARD VICKERS pointed out that, if it were not for the fact just referred to—that wrought-iron, or steel containing little carbon, would take carbon from harder or more highly carbonised material under the conditions described,—it would not be possible to carry out the old process of cementing steel, nor the converse process of making malleable iron from cast-iron castings.

Sir FREDERICK ABEL said Mr. Vickers had very truly remarked that the observations referred to by Mr. Bell and Mr. Paget lay at the root of the cementing, case-hardening, and other analogous processes. The facts referred to by those gentlemen had been borne out by the results obtained from the examination of the discs of steel which had been annealed between wrought-iron and cast-iron plates, as he had endeavoured to point out in this Report. In the use of wrought-iron plates there was undoubted evidence of removal of carbon from the steel; while on the other hand when using cast-iron there was undoubted evidence of the addition of carbon. The amount of carbon was not actually large, but was large comparatively, that was transferred to or from the steel by simply heating at a temperature considerably below fusion, between either cast-iron or wrought-iron plates. About twenty-five years ago he had had

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(Sir Frederick Abel.)
occasion to make experiments with a view to ascertaining whether he could discover a ready means, by simple treatment with acids, of distinguishing between annealed and hardened wires, or of distinguishing different degrees of annealing or hardening of wires; and he obtained results very similar to those described by Mr. Dugard as having been obtained not long since by Professor Norris: results which, when the Committee were in a difficulty in regard to the direction in which they should work, had led him to hope that possibly by pursuing a similar line of research he might hit upon a simple chemical method by which differences of temper in different pieces of steel might be ascertained. It was that hope which had led him to take up the research which had branched away from his original point; and it was only incidentally that he had referred to the various mechanical or physical conditions in which the carbon of annealed, hardened, and tempered steel was left after treatment by acid solvents, as indicating that some method of that sort might perhaps still be hoped for, if the investigations were continued. He regretted that his own numerous duties—professional, scientific, official—rendered it impossible for him to carry out to a further extent these extremely laborious investigations. He did think it might be desirable however that any gentlemen who combined chemical with metallurgical knowledge should pursue experiments on the foundation of the reports presented by the Steel Committee, and endeavour to elaborate still further the indications there given of possible differences which might be discovered by comparatively simple means between steels in different conditions of temper.

As regarded the nature of the colours produced by different tempers, he was sorry to say that up to the present time the knowledge on this point was extremely small. There was no doubt that some minute film was produced on the surface. The treatment of the surface with acid removed the colour immediately; but the film was so minute that it would be necessary to operate upon very large quantities indeed, and even then there could not be any certainty that the action of the solvents on the iron beneath the minute film would not altogether disguise the results obtained

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by the solution of the film itself. Therefore he feared that, from a chemical point of view, there was little chance of light being thrown on the nature of different films that indicated different degrees of temper. It was sad for him as a chemist to have to confess that up to the present time chemical knowledge was very restricted in its operation in this direction. He only hoped, with Mr. Bell, that, as they were still only on the threshold of this subject, perseverance in connection with these investigations might in course of time, especially if taken up by various workers, lead to fruitful results.

The PRESIDENT said that the Report to which they had just listened was one of which the Institution of Mechanical Engineers might well be proud. He therefore moved that the best thanks of this meeting be given to Sir Frederick Abel for his most valuable Report.

The vote of thanks was carried unanimously.

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RESEARCH COMMITTEE ON FRICTION.

SECOND REPORT ON FRICTION EXPERIMENTS.

BY MR. BEAUCHAMP TOWER, OF LONDON.

Experiments on the Oil Pressure in a Bearing.

These experiments were tried with a brass similar to that which had been used for the Friction Experiments previously conducted by the Research Committee of this Institution (see Proceedings 1883, pp. 638-9). The bearing was 4 inches diameter and 6 inches long. The brass did not embrace quite half the journal, having been reduced till the chord of the arc of contact was 3·9 inches, as shown in Figs. 1 and 2 in the accompanying Plate facing page 60.

Three $\frac{1}{4}$-inch holes were drilled lengthwise in the body of the brass, and through a little more than half its length, Fig. 1. One of them was in the centre, and the other two were one on each side of it, Fig. 2. These holes coming out at one end of the brass were connected by converging copper pipes to a Bourdon pressure-gauge. In order to ascertain the pressure at any point between the brass and journal, a hole $\frac{1}{16}$ inch diameter was drilled from the bearing surface of the brass into one of these longitudinal holes, thus establishing a connection between that point and the pressure-gauge. The pressure having been ascertained, the hole was stopped and another hole drilled, and so on.

The arrangement of the holes which were successively tested was as follows. The brass was supposed to be divided by six vertical planes, three of them parallel to the axis of the journal, and three at right angles to it; and the test holes were situated at the nine points of intersection of these planes. The planes parallel to the axis of the journal were 0·975 inch apart, Fig. 2, so as to divide the brass longitudinally into four parts of equal breadth. Of these three planes, one passed along the axis of the journal, and was called the "centre plane." One was on the side where the surface of the

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journal entered the brass, and was called the "on plane," the direction of rotation of the journal being indicated by the arrow in Fig. 2. The other on the side where the surface of the journal left the brass was called the "off plane." Of the three transverse planes, Fig. 1, one was in the centre of the length of the brass, and was called the "middle plane;" the other two were each one inch apart, and divided the brass from the middle to the end into three transverse slices of one inch length. The plane nearest the middle was called No. 1, and the furthest No. 2. The position of any one of the nine holes can thus be easily described by naming the two planes at the intersection of which it was situated.

The pressure was thus actually read off at nine places in the bearing; but as it is reasonable to suppose that the pressure must be symmetrically disposed on either side of the middle transverse plane, Fig. 1, the pressures were observed on one side only of that plane, and those on the other side were assumed to be the same: so that in reality the pressure may be considered to have been ascertained in fifteen places distributed over the whole bearing surface of the brass.

The bearing had a total load of 8,008 lbs. on it, and the journal rotated at 150 revolutions per minute. The temperature throughout was 90° Fahr. The observed oil pressures were as follows in lbs. per square inch.

TABLE XII.—*Oil Pressure at different points of a Bearing.*

Longitudinal Planes . . .	On.	Centre.	Off.
Pressure per square inch . . .	Lbs.	Lbs.	Lbs.
Transverse Plane, Middle . .	370	625	500
" " No. 1 . .	355	615	485
" " No. 2 . .	310	565	430

Curves drawn by using these figures as ordinates are shown in Figs. 1 and 2 in the accompanying Plate. Their most clearly marked feature is seen to be that the place of greatest pressure is on the "off" side of the centre, Fig. 2, the pressure at the holes in the "on" side being in every case considerably less than that at the corresponding holes on the "off" side. The total upward force exerted by these pressures is 7,988 lbs., or within 20 lbs. of the actual load of 8,008 lbs.; this very small difference between the load and the oil pressure is probably due to errors of observation.

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In order to wear the brass down to a perfect fit on the journal, the bearing was first run for some time with a heavier load than that with which the experiments were taken. It was found that in taking off or putting on weight the pressure fell or rose exactly in proportion to the load. At the end of the experiments the speed of the journal was reduced from 150 revolutions per minute to 20; but the pressure-gauge indicated exactly the same pressure with both speeds.

The oil used was a heavy mineral oil, the journal being about half immersed in a bath of it.

Experiments on Friction at a Low Speed.

After the completion of the oil-pressure experiments, the speed was reduced to 20 revolutions per minute; and observations of the amount of friction at this speed with various loads were made with the journal running about half immersed in a bath of mineral oil. By this time the brass had become by wear a very perfect fit on the journal: so perfect that, after stopping the journal, the pressure indicated by the pressure-gauge fell very slowly; on one occasion it took about half an hour for the pressure to fall from 600 lbs. per square inch to zero. The pressure indicated by the pressure-gauge at 20 revolutions per minute was the same as that at 150, thus showing that the brass was as completely oil-borne at the lower speed as it had been at the higher.

The friction was very nearly the same as that obtained in the former experiments with the same kind of oil at 200 revolutions per minute. The following was the observed friction.

TABLE XIII.—*Friction of a Bearing 4 inches diameter and 6 inches long, running at 20 revolutions per minute in a bath of Mineral Oil. Chord of arc of contact of brass, 3·9 inches. Temperature 90° F.*

NOMINAL LOAD. Lbs. per sq. inch.	COEFFICIENT OF FRICTION at 20 revs. = 21 feet per min.
443	0·00132
333	0·00168
211	0·00247
89	0·0044

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To face page 60.

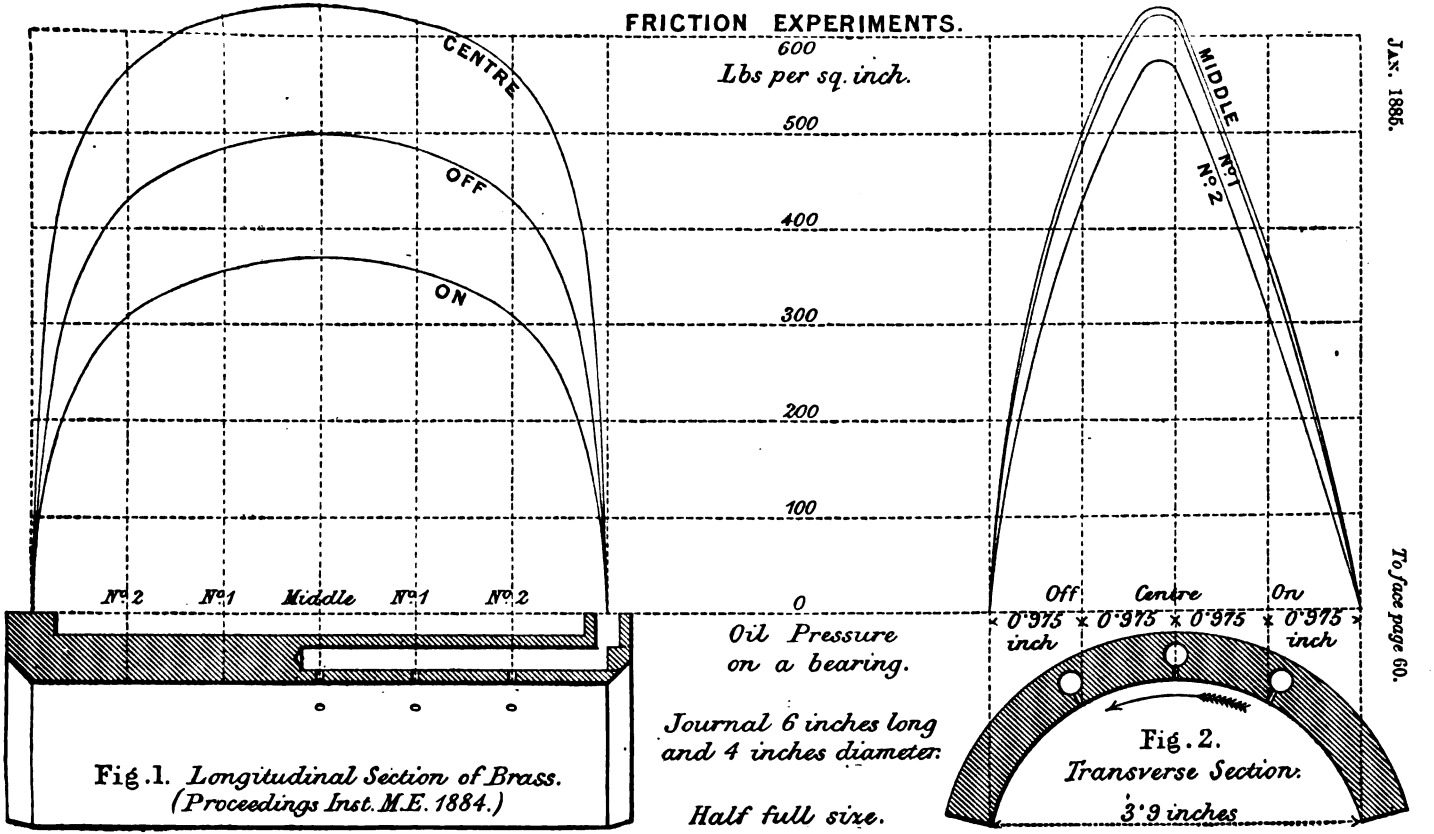

Fig. 1. *Longitudinal Section of Brass.*
(Proceedings Inst. M.E. 1884.)

Fig. 2.
Transverse Section.

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From these figures it is seen that, while the load was reduced from 443 lbs. down to 89 lbs. per square inch, or in the ratio of 5 to 1, the coefficient of friction rose from 0·00132 up to 0·0044, or in the ratio of 1 to $3\frac{1}{3}$.

The nominal load per square inch is the total load divided by the product of the diameter and length of the journal; that is to say, it is in this case 1-24th of the total load. At the same low speed of 20 revolutions per minute it was increased to 676 lbs. per square inch without the slightest signs of heating or seizing.

Discussion.

Mr. JOSEPH TOMLINSON explained that the first series of experiments (Proceedings 1883, pp. 632–652) had led to the second now described, in consequence of the difficulty which had been experienced of feeding the journal with lubricating material from the top, when there was a heavy load on the bearing. It had then been suggested by Mr. Tower and himself that they should find out what the pressures were in an upward direction; and the present Report simply recorded the results of the experiments made with this object. It was very interesting to discover that, after the load on the bearing had risen to something like 200 lbs. per square inch, the oil could no longer be fed from the top; it would not then go down, and the bearing seized almost immediately. But by oiling from the bottom the load had been increased up to 625 lbs. per square inch, by putting on all the load that could be got into the framework of the experimental apparatus, and at high velocities they had succeeded in running with that load; but when it was again attempted to feed from above, the efforts entirely failed with the heavy load that had been put on. That was the way in which this second series of experiments had originated, and he thought the results were very interesting. The chief advantage derived from the experiments was that they showed that, if the bearing was perfectly lubricated by immersion in a bath, almost any load might be put on.

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Mr. BEAUCHAMP TOWER said the experiments detailed in the Report that had just been read were supplementary to the former experiments, in which the curious discovery had been made that between the brass and the journal there was an actual oil pressure which could be indicated by a pressure-gauge. A remarkable confirmation was thereby afforded of the theoretical conclusion to be derived from the previous experiments, namely, that it was possible to make the brass on a journal work so nicely that there should be absolutely no metallic contact between the journal and the brass, the whole of the weight being borne by the oil. It seemed to him that the important practical inference was that it was actually possible so to lubricate a bearing that not only would metallic friction be altogether done away with, and thereby the amount of power lost by friction be reduced, but metallic wear and tear would also be done away with. He would not say that such a result was actually possible in practice now; but it was a reasonable one to aim at in mechanism. By giving a sufficiently profuse lubrication, and by having the brasses so arranged that there should be a uniform pressure all over their surface, it was possible to have wear and tear between metal and oil, instead of between metal and metal.

Mr. CHARLES COCHRANE mentioned that in a recent visit to the North Eastern Railway locomotive and wagon shops at Darlington he had noticed a plan there adopted for getting over this difficulty of feeding the axles from the top. The journals were there boxed in underneath in such a way as to allow of supplying to the underside of the journal the oil necessary for lubricating. He had mentioned the fact of these friction experiments to the engineer, who had been much pleased to find that the plan which he himself had applied practically was borne out theoretically.

Mr. JOHN ROBINSON could confirm from experiments made long ago what Mr. Tower had said about avoiding actual metallic contact, by the oil preventing contact between the brass and the iron. This avoidance of contact by an intervening fluid had fallen under his own observation many years ago, when set during his apprenticeship to

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file and scrape surface-plates. His old master, Mr. Roberts, as was well known, was a very exact mechanic; and one thing that he set his apprentices to do was to produce very accurate surfaces. They had at that time surface-plates weighing perhaps 25 lbs. each, and he had often seen one plate put on the other—as no doubt many other engineers had seen too—when no contact existed between the upper and the lower plate, the upper being wholly floated upon a stratum of air which remained between the two surfaces; and if air would so resist that pressure, it was much more easy for oil to do so.

Mr. DANIEL ADAMSON had had some experience in the lubricating of journals, and under very much heavier pressures than those mentioned in the Report. Under ordinary circumstances he should not think there would be much difficulty in carrying out the lubrication of a journal from beneath, as now recommended from these experiments; but it had been pointed out in the Report, and he thought most excellently, that with an exceedingly well fitting journal there was a difficulty to get oil in between. It was generally recognised that the oil acted as a lubricant by merely furnishing atoms rolling in between the two surfaces; but unless the atoms could be got in between, there was no possibility of the diminution of friction. The most difficult case was that of lubricating the footstep of an upright shaft carrying a heavy load. Supposing there were an upright shaft of 5 inches diameter, or say 20 square inches area, then in practice 20 tons could certainly be carried on the footstep of such a shaft; and 2240 lbs. per square inch was a very different thing from the limited pressures mentioned in the Report. But in such a case, instead of using thin mineral oil, he would mix fatty oil with the mineral oil, so as to get it more manageable. His latest experience, which had been very satisfactory both to himself and to others, was not to attempt to oil at the top a bearing under heavy pressure, because practically, as was set forth in the Report, the oil could not be got in so. If the difficulty was to be entirely got over, the oil must be got in at the bottom, and for that purpose a pump must be used. By that means the difficulty of working an upright shaft under a very heavy load, and at much higher speed

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(Mr. Daniel Adamson.)

than the revolutions reported in the paper, was very easily got over. The oil should be put in at the centre of the footstep of an upright shaft, because the centrifugal action had a tendency to run it to the outside; and it was clear that the first supply of the oil to the metal surfaces should be at the point where it was most needed. He had tried to get the oil underneath the foot of the upright shaft, when running with anything like one ton per square inch, by means of a surrounding cistern of oil, and had failed many times. The system of feeding by pump was neither difficult nor expensive, because the same oil was pumped in over and over again, and the heavily pressed journal would go on working well, and very little expenditure of oil would take place. This had been his own daily experience, the pump having been the means of obviating the whole trouble of such heavily loaded journals, where previously the lubricant could not be got into the right place.

Mr. WILLIAM SCHÖNHEYDER asked whether the friction experiments were going to be continued, and if so whether experiments ought not to be made upon journals more heavily loaded than those mentioned in the Report. Engineers all liked to provide very liberal journals and to have very light loads per square inch, but it was not always possible to do so; and they would like to know how journals behaved when weighted with heavier loads than 600 lbs. per square inch.

Another point which he considered ought to be brought more clearly to light was the difference between the load a journal could carry when the load was continuously on it, as for instance in the axles of railway carriages, and when the load was intermittent. It was well known from practical experience that with a constant load on an ordinary journal it was difficult and almost impossible to have more than 200 lbs. per square inch, otherwise the bearing would get hot and the oil go out of it; but when the motion was reciprocating, so that the load was alternately relieved from the journal, as with crank-pins and similar journals, much higher loads might be applied than even 700 or 800 lbs. per square inch. If these experiments

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were to be continued, it seemed to him that it would not be difficult to have the load intermittently relieved from the bearing, and in that way to find out what the friction then was and what loads could actually be carried.

Mr. EDWARD REYNOLDS said, with regard to Mr. Robinson's observation about surface-plates floating on the air held between them, the converse of that also existed. It was very easy indeed to get rid of that film of air, and then the plates stuck together. As much as forty years ago he had found out that it was easy to make the slide-blocks of locomotives too long, because the leading part of the blocks then swept away the oil, and left the tail part dry. That was now got over by grooving; and within his own knowledge it had been found necessary to groove the journals of axles, as well as their brasses, so that the groove in the journal might have a chance of picking up the oil as it passed, and of carrying it from the bottom up into the bearing or from groove to groove in the brass. A friend had one day called his attention to a case bearing strongly upon this point, when he happened to be looking at some planing machines made with flat beds, for the sake of having rectangular sides to the bed for resisting side cuts. His friend seeing those machines had advised him to have the faces scraped of the beds; and on his remonstrating that they could not be a better fit than they then were, the reply he received was "That is exactly what is the matter; it is too good a fit." There were very many cases of slide-bars and rubbing surfaces of that kind, which worked on for ever so many years before the scraper marks were gone; and then all at once they began to cut, because the scraper marks were gone. It did not do to have exceedingly well-fitting surfaces, for high speeds at any rate. It was exceedingly difficult to keep the film of lubrication in; and that was the object always to be aimed at. The fact had been known in the abstract for a long time that a surface could be floated on a film of liquid, or even of air, interposed between itself and another surface; the difficulty was to point out some means by which that fact could be practically utilised.

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Mr. GEORGE RICHARDS observed that neither in the Report, nor thus far in the discussion upon it, had any reference been made to the life of the oil used for lubrication. This would of course be modified by the nature of the oil used: that is, whether it was a mineral oil, or whether of animal or vegetable origin. Animal and vegetable oils underwent a gradual chemical change when exposed for a long time in thin films to the air; their glycerine was separated, and they were converted into fatty acids. Several years ago some experiments had been tried by Mr. Isherwood, of the United States Navy, in which the power developed by steam engines was tested by making them drive a number of fans at a certain speed. The bearings of the fans were kept flooded with lard oil, and the overflowing oil was filtered and used over and over again for several months. A doubt having been suggested as to whether the lubricating power of this oil remained unchanged in its repeated use, the experiment was tried of replacing it by fresh oil, all other conditions remaining the same. The speed of the fans was observed to increase immediately; and after a few minutes, when the fresh oil had completely displaced the old in the bearings, another fan had to be thrown on in order to bring the speed down to its normal rate. It would seem therefore that in the case of lard oil, and probably of all animal and vegetable oils, the freshness of the oil had a considerable influence upon its lubricating power.

Mr. JOSEPH TOMLINSON said, in reference to the life of oil, he had had a carriage running until a few months ago on the Metropolitan Railway with brass bearings, which had run about 29,000 miles a year with the same bearings for ten years; and the average amount of oil put in during the whole time was one pint per annum per journal. The journals were lubricated from the bottom.*

The PRESIDENT pointed out that in these experiments a kind of bearing had been selected which was not the most frequent in general use, namely a hanging bearing, that is, a bearing going over the top

* Proceedings Institution of Civil Engineers, 1878, vol. liii, page 86.

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of a shaft, which shaft also was quietly revolving. The axle-boxes in railway trains differed, in that they were all in a state of vibration, which probably allowed the oil to pass freely round. There were very few examples in ordinary work where the bearing was on the top, with a heavy load hanging from it, and without any vibration whatever. The Report, though brief, he thought was a very valuable one; and he for one certainly trusted that the Friction Committee would continue their investigations. They had quite revolutionised in many ways the notions that had previously prevailed with regard to friction. He remembered when a student that the experiments of the late General Morin were those which were generally quoted. In those experiments several different metals were taken, and after their surfaces had been oiled they were wiped nearly dry and were then experimented upon to find what the friction was. Roughly speaking it was something like one-tenth of the load; as the load increased or diminished, the friction on the same surface was supposed to increase or diminish in the same proportion. The point was that the surfaces were always wiped nearly dry after being oiled. In a note appended to the account of those early experiments it was mentioned that if the bearing was fully supplied with oil it was more a question of the nature of the oil than of the nature of the metals. The experiments described in the present Report seemed rather to confirm that view, because if the bearing was entirely oil-borne the question would naturally be asked, "Does it really matter what the bearings are made of?" These experiments would have been quite a failure if the device had not been hit upon of making the bearing revolve in a bath of oil below. That made all the difference between the impossibility of lubricating the journal at all, and the ability to do it in such a way as to float it in oil altogether. This result was extremely suggestive, and might lead to a revolution in the way of oiling bearings. It gave still more importance to the nature of the oil used, when it was found that the bearings were oil-borne. As Mr. Adamson had pointed out, the same conclusion seemed to have been arrived at by others. Oil had in several cases been pumped continuously into bearings in such a way as to keep them floating in oil. He believed the Hon. Mr. Parsons did this in his fast-running engine made at Messrs.

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(The President.)

Kitson's at Leeds; and Mr. Heenan also did it in the inside of the Tower spherical engine. He thought the Members would all agree that these experiments upon friction had proved most valuable, and that it was most desirable they should be continued.

Mr. ARTHUR PAGET asked the President's permission to say that he thought they should not be fulfilling their duty if they did not pass a hearty vote of thanks to the gentleman who had done the major part of the work and had contributed so largely to the success of the Committee's experiments. He alluded to Mr. Tomlinson, who had conducted the experiments almost at his own cost, and had given an amount of time and devotion to the subject which he was sure the Institution would gladly recognise. He therefore proposed that a vote of thanks be given to Mr. Tomlinson for his valuable labours, which had resulted in the Report that had just been read.

The PRESIDENT had great pleasure in putting the motion, which he thought was most opportune and well merited.

The motion was carried unanimously.

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MEMOIRS.

THOMAS BALDWIN was born at Bolton, Lancashire, on 10th March 1822. After being educated at the Grammar School there, he served an apprenticeship to Messrs. Richard Walker and Sons, engineers and ironfounders, Bury, for seven years, during which he continued his studies under the head-master of the Bury Grammar School. After a time he commenced business for himself as a consulting engineer in Bury; and he was for many years a director of the Bury Athenæum, in which he also taught classes in algebra, chemistry, and other subjects. At a later date he was engaged in South Wales in making the Llynvi Valley Railway of about twelve miles length from Bridgend to Maesteg; after which he returned to Bury, where he erected one or two cotton mills. Subsequently he removed to Manchester, where unfortunately his health began to fail; and his death took place there on 27th September 1884, in the sixty-third year of his age. He became a Member of the Institution in 1879, being at that time the chief engineer of the Mutual Boiler Insurance Co., Manchester.

JOHN BUTLER, elder son of the late Mr. Joseph Butler, was born on 25th April 1822, at Bowling, where his father had served his apprenticeship as a moulder. In July 1828 his father removed to Stanningley near Leeds, and in partnership with two or three others commenced business in a small way as ironfounders. After a few years, the firm added to their business that of engineering and railway-plant manufacturing; and it was during this time that Mr. John Butler acquired his practical knowledge there. In 1838 the business was taken over and carried on by Mr. Joseph Butler alone, who with his son turned their attention to the manufacture of iron bridges, the first they made being those required for the Leeds and Selby Railway; subsequently they supplied the bridges for

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several other railways, including the cast-iron bridge spanning the river Ribble at Preston, and very many others, both in this country and abroad; also the ironwork for the roof of the new station at York, and for numerous other large structures. To Mr. John Butler's exertions are mainly due the development and prosperity of the Stanningley Iron Works, now carried on by his sons, which at the time of his death employed from eight hundred to a thousand workmen. He died at his residence, West Royd, Farsley, on 17th October 1884, at the age of sixty-two, and was interred at the little church of Farsley. He became a Member of the Institution in 1859.

DAVID HARDMAN FLETCHER was born in Manchester on 23rd October 1847, and was the youngest son of the late Mr. James Fletcher, of Messrs. William Collier and Co., engineers and machine-tool makers, Salford, who was a Member of this Institution till his death in 1881. At the age of sixteen he was placed in the office of these works, of which his father was then the sole proprietor; and in 1875 he was made a partner in the firm, along with his two elder brothers. Owing to a serious defect in his eye-sight he was unable to acquaint himself practically with the manufacture of machine-tools; but by constant study and assiduous attention he became thoroughly acquainted with their principles, and his theoretical knowledge was on many occasions of great service. The active part he took in the business consisted mostly in travelling in this country and abroad in connection with the firm, and in the management of the financial department. He died on 18th March 1884 at the age of thirty-six, after a protracted illness. He became a Member of the Institution in 1882.

JAMES KERR was born in Glasgow on 14th April 1851. After leaving the university, where he had studied in arts, he was for about three years with Messrs. Snell Stuart and Co., Glasgow, rolling-stock contractors, and had the designing and inspecting of the rolling stock supplied by them. Subsequently for ten years he carried on business on his own account as a contractor and designer of rolling stock, and latterly was managing and senior partner in the firm of

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Messrs. Kerr Stuart and Co., London and Glasgow, manufacturers of portable and narrow-gauge railway plant. He invented several improvements in connection with that class of railway plant, and himself designed and completed seventy miles of light-railway permanent way with rolling stock for the Prince of Morvi. He died on 4th December 1884, at the early age of thirty-three. He became a Member of the Institution in 1884.

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Institution of Mechanical Engineers.

PROCEEDINGS.

March 1885.

An Ordinary General Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Friday, 20th March 1885, at Half-past Seven o'clock p.m.; Jeremiah Head, Esq., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the seven following resignations of seats on the Council had been received, and had been accepted by the Council with regret: — Mr. Westmacott, Past-President; Mr. Anderson, Mr. Crampton, and Mr. Rennie, Vice-Presidents; Mr. Boyd, Mr. Kitson, and Mr. Tweddell, Members of Council.

In accordance with No. 28 of the Articles of Association, the vacancies thus occurring had been filled up by the Council until the Annual General Meeting in next year. As Vice-Presidents the Council had appointed the three following Members of Council:—

VICE-PRESIDENTS.

E. Hamer Carbutt, M.P., . . .	London.
David Greig, ...	Leeds.
Joseph Tomlinson, Jun., . . .	London.

There were six consequent vacancies among the Members of Council, for which the Council had been engaged during a great part of their meeting that afternoon in selecting suitable names of Members. There were so many Members who in the opinion of the Council were worthy to occupy the position, that the selection had required considerable time and considerable pains. The names

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which had finally been selected would be duly announced, as soon as their acceptance of the appointment had been ascertained.

Their acceptance having since been ascertained, the following are the six Members of Council appointed:—

MEMBERS OF COUNCIL.

PETER D. BENNETT, ...	Tipton.
WILLIAM DENNY, F.R.S.E., . . .	Dumbarton.
SIR JAMES N. DOUGLASS, . . .	London.
EDWARD B. MARTEN, . . .	Stourbridge.
BENJAMIN WALKER, ...	Leeds.
J. HARTLEY WICKSTEED. . . .	Leeds.

The PRESIDENT announced that the Members were kindly invited by the Royal Meteorological Society to inspect the collection of meteorological instruments exhibited by the Society in the library adjoining.

The following Papers were read and discussed:—

On recent improvements in Wood-Cutting Machinery; by Mr. GEORGE RICHARDS, of Manchester. (Adjourned Discussion.)

Description of the Tower Spherical Engine; by Mr. R. HAMMERSLEY HEENAN, of Manchester.

On the History of Paddle-Wheel Steam Navigation; by Mr. HENRY SANDHAM, of London.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated. The attendance was 55 Members and 36 Visitors.

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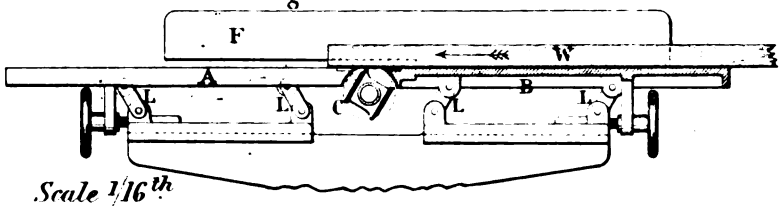
WOOD-CUTTING MACHINERY. *Plate 1.*

Planing Machine.

Fig. 1. *Elevation.*



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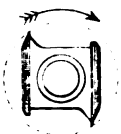
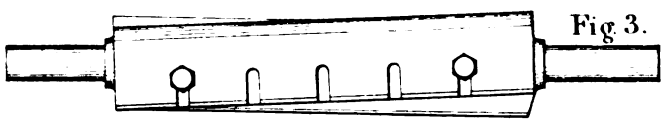
Cutters and Cutter-Blocks.

Fig. 2.



Scale 1/8th

Fig. 3.



Guard on Planing Machine.

Fig. 4. *Elevation.*

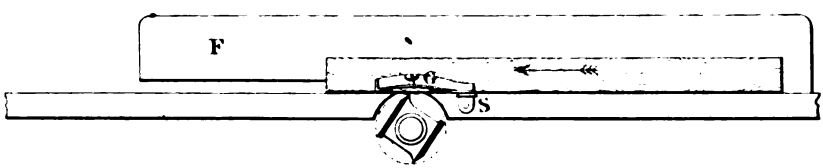
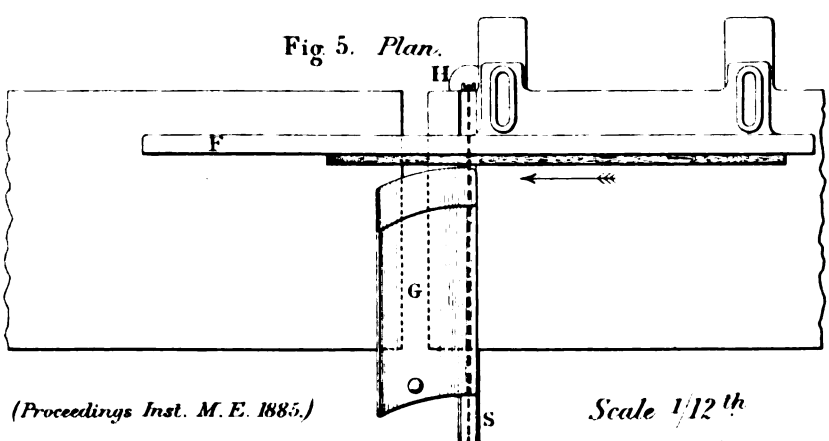


Fig. 5. *Plan.*



(Proceedings Inst. M. E. 1885.)

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Dimension-Sawing Machine.

Fig. 6.

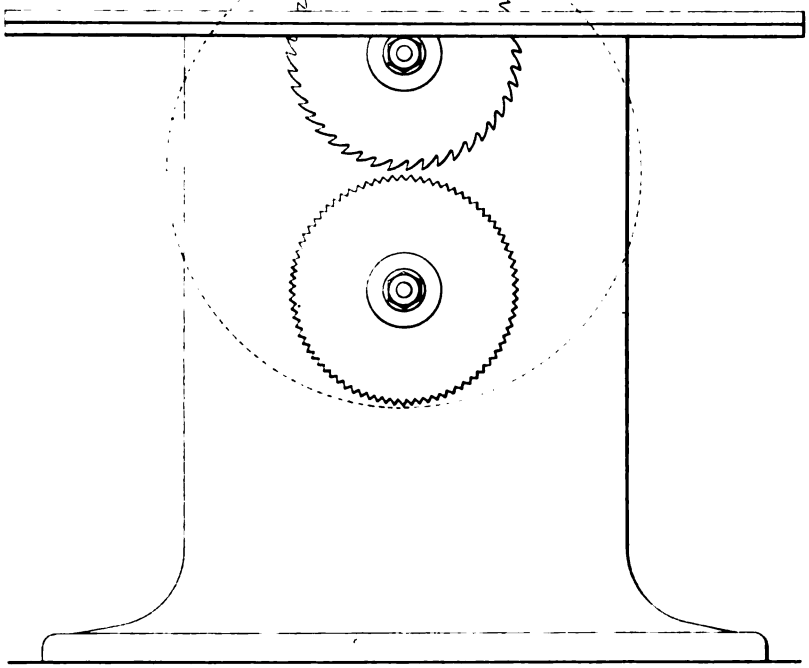
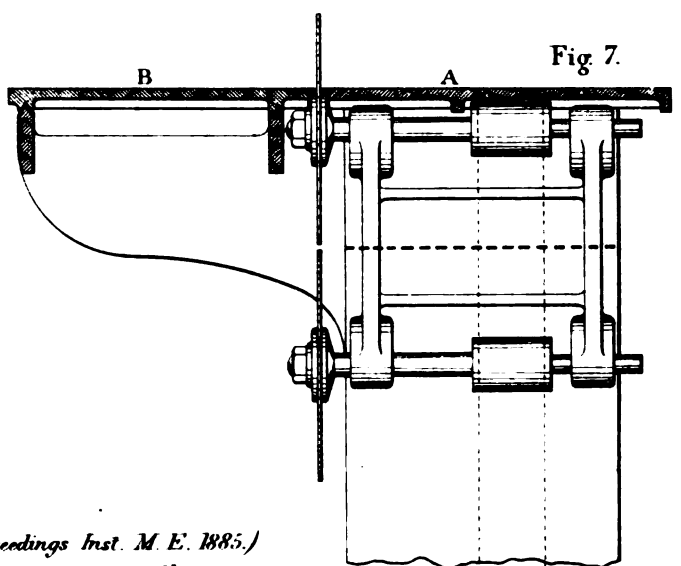


Fig. 7.



(Proceedings Inst. M. E. 1885.)

Scale 1/10th.

10 5 0 10 20 Inches.

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Dimension-Sawing Machine.

Fig. 8.
Saw cutting.

Saw idle.

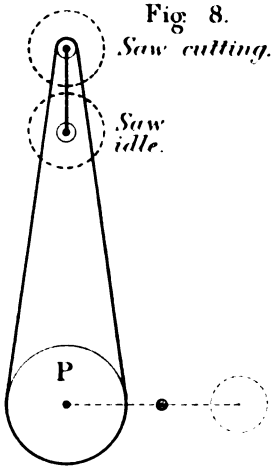
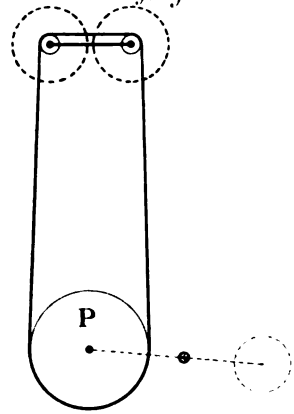


Fig. 9.
Saws changing.



Scale 1/30th

Fig. 10. *Section of Saw.* *Scale 1/3rd.*

Eccentric Die for setting Saw Teeth. *Scale half size.*

Fig. 12. *Elevation.*

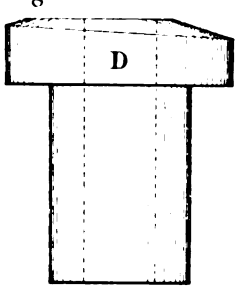


Fig. 13. *Plan.*

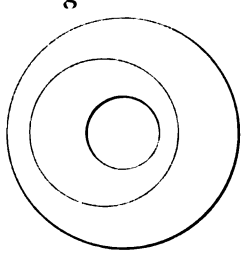
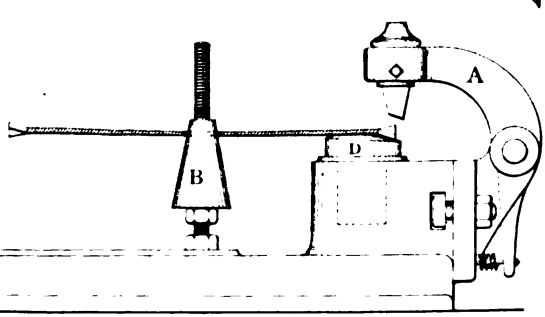


Fig. 11.
Scale 1 6 th



(Proceedings Inst. M. E. 1885.)

Scale 1 6th

0 5 10 15 20 Inches.

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WOOD-CUTTING MACHINERY.

Plate 4.

Wood Blocks cut by Dimension-Sawing Machine.

Fig. 14.

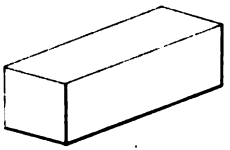


Fig. 15.

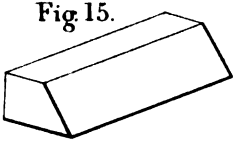


Fig. 16.

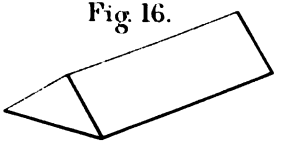


Fig. 17.

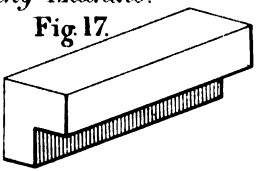


Fig. 18.

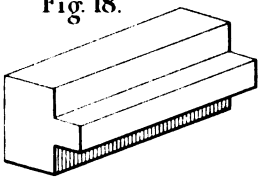


Fig. 19.

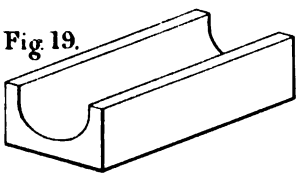


Fig. 20.

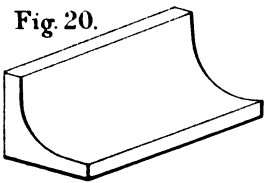


Fig. 21.

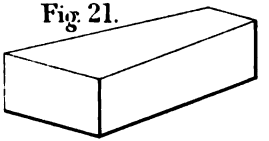


Fig. 22.

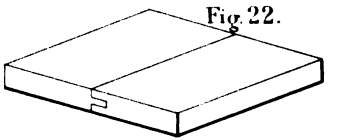


Fig. 23.

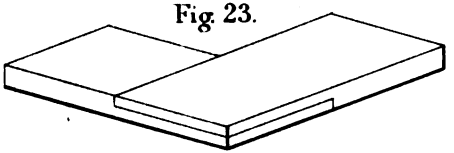


Fig. 24.

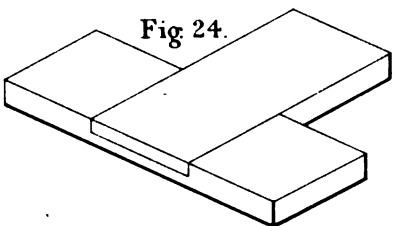


Fig. 25.

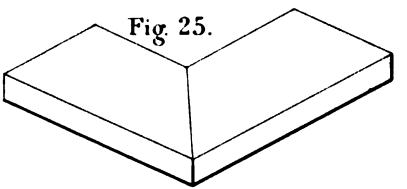


Fig. 26.

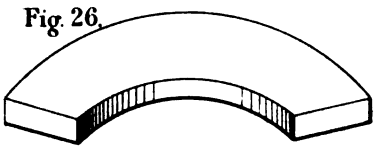


Fig. 27.

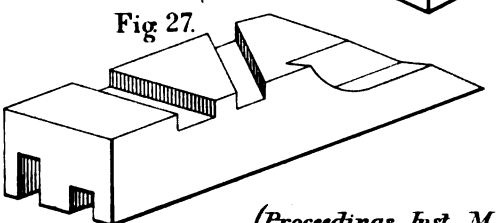
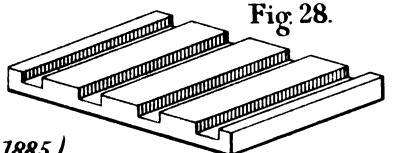


Fig. 28.



(Proceedings Inst. M. E. 1885.)

Plate 4.

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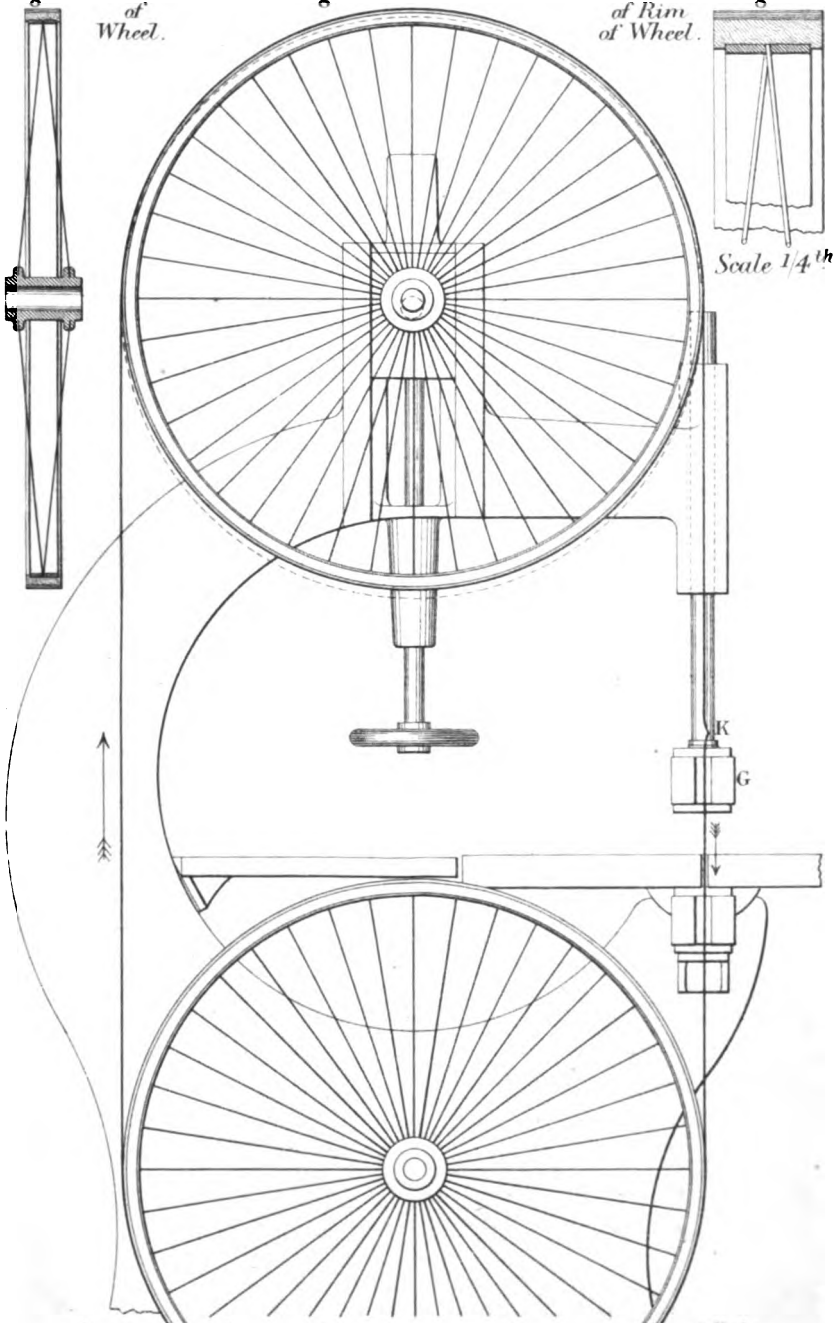
WOOD-CUTTING MACHINERY. *Plate 5.*

Band-Sawing Machine.

Fig. 30. *Section of Wheel.*

Fig. 29. *Elevation.*

Section of Rim of Wheel. Fig. 31.



Scale 1/4th

Scale 1/12th.

(*Proceedings Inst. M. E. 1885.*)

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Guides for Band-Saw.

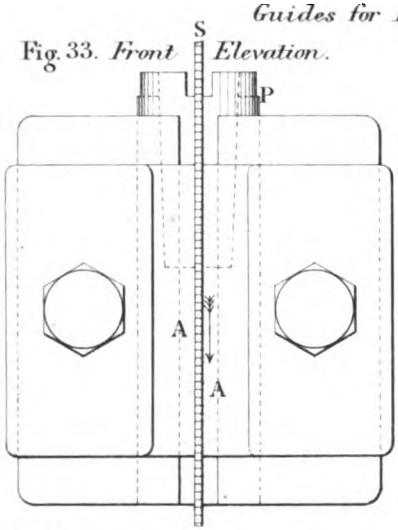

Fig. 33. *Front Elevation.*

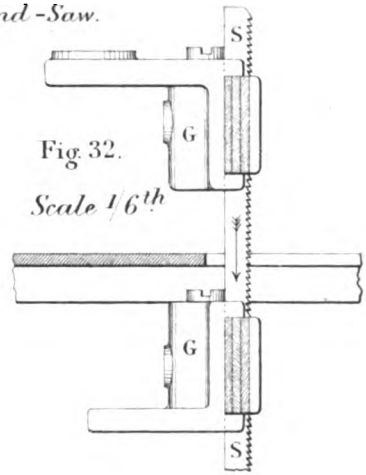

Fig. 32.

Scale 1/6th

Scale half full size.

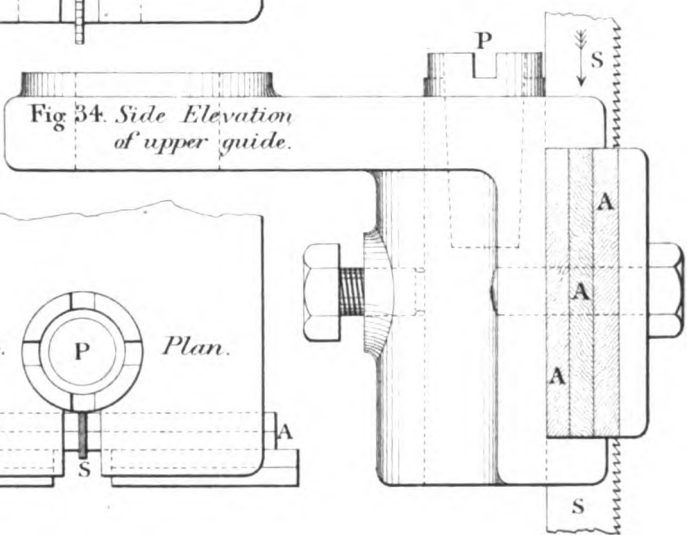

Fig. 34. *Side Elevation of upper guide.*

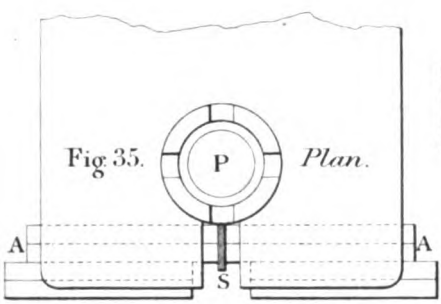

Fig. 35. *Plan.*

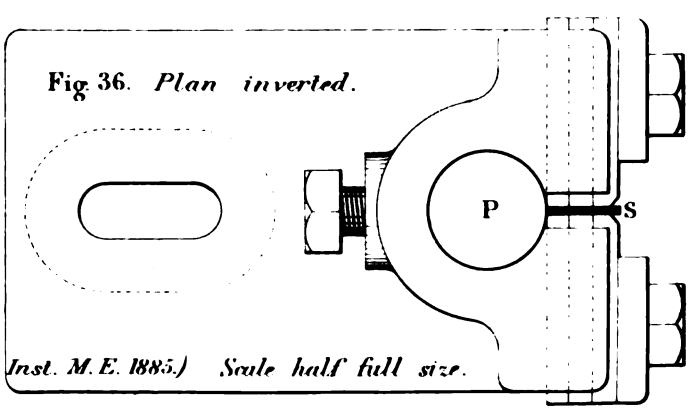

Fig. 36. *Plan inverted.*

(*Proceedings Inst. M.E. 1885.*) *Scale half full size.*

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Cutter-Grinding Machine.

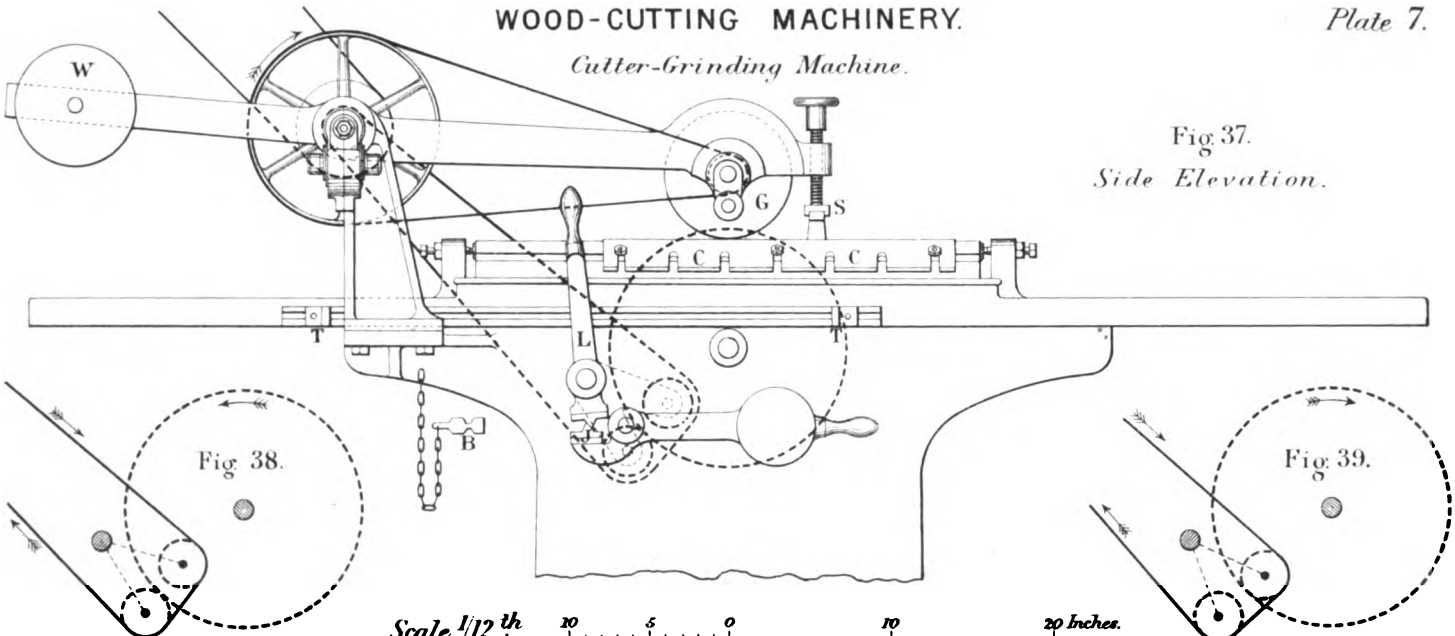

Fig. 37.
Side Elevation.

Fig. 38.

Fig. 39.

Scale 1/12th 10 5 0 10 20 Inches.

Fig. 40. *Traversing of Table by Wire Cord.*

(Proceedings Inst. M. E. 1885.)

Plate 7.

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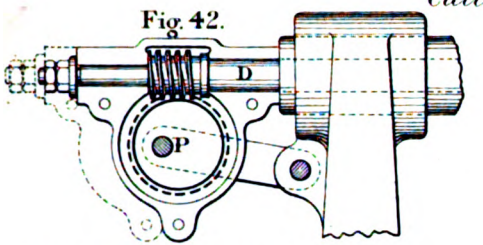
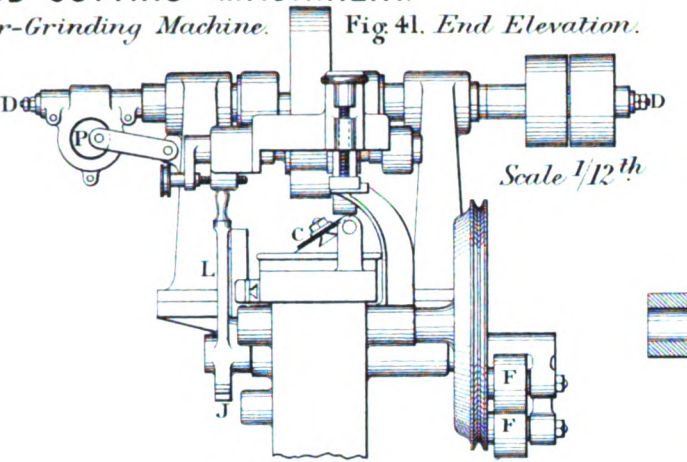
Cutter-Grinding Machine.

Fig. 42.



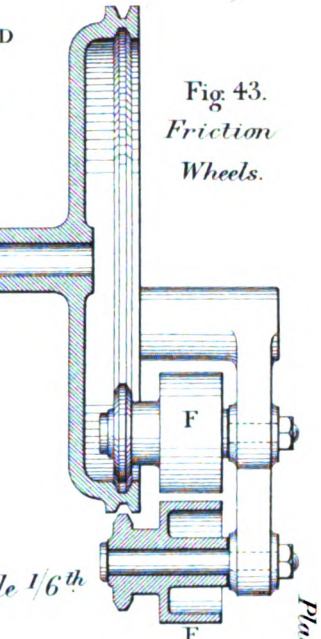
Lateral Traversing Gear.
Scale 1/6th

Fig. 41. *End Elevation.*



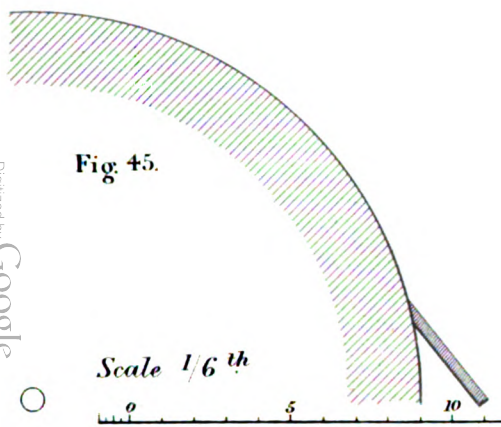
Scale 1/12th

Fig. 43.
Friction Wheels.



Scale 1/6th

Fig. 45.



Scale 1/6th

0 5 10 15 20 Inches.

Fig. 46.

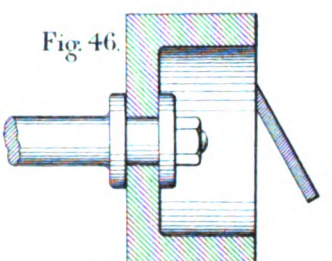


Fig. 44.

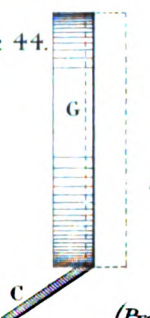


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Plate 8.

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Panel-Planing Machine.

Fig. 47. *Section.*

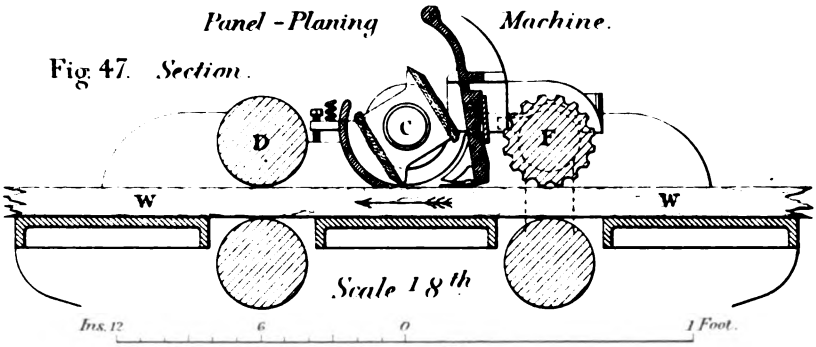
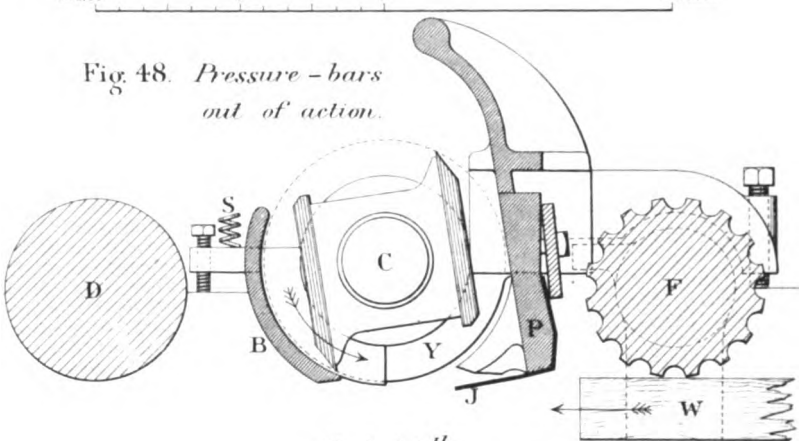


Fig. 48. *Pressure-bars out of action.*



Scale 1 4th

Fig. 51. *Back Pressure-bar.*

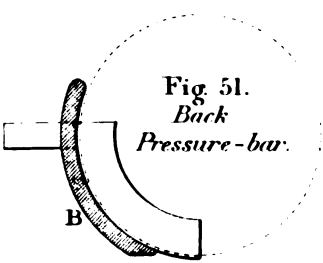


Fig. 50. *Front Pressure-bar.*

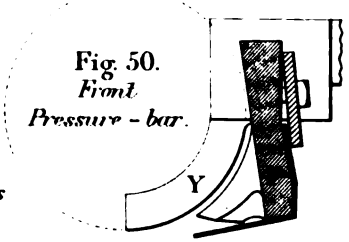
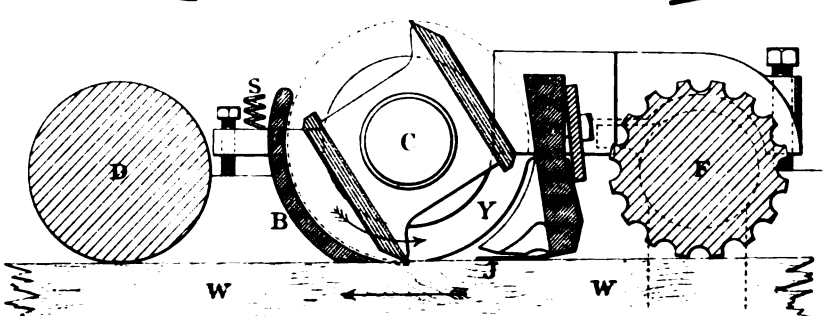


Fig. 49. *Pressure-bars in action.*



(Proceedings Inst M.E. 1885.)

Scale 1 4th

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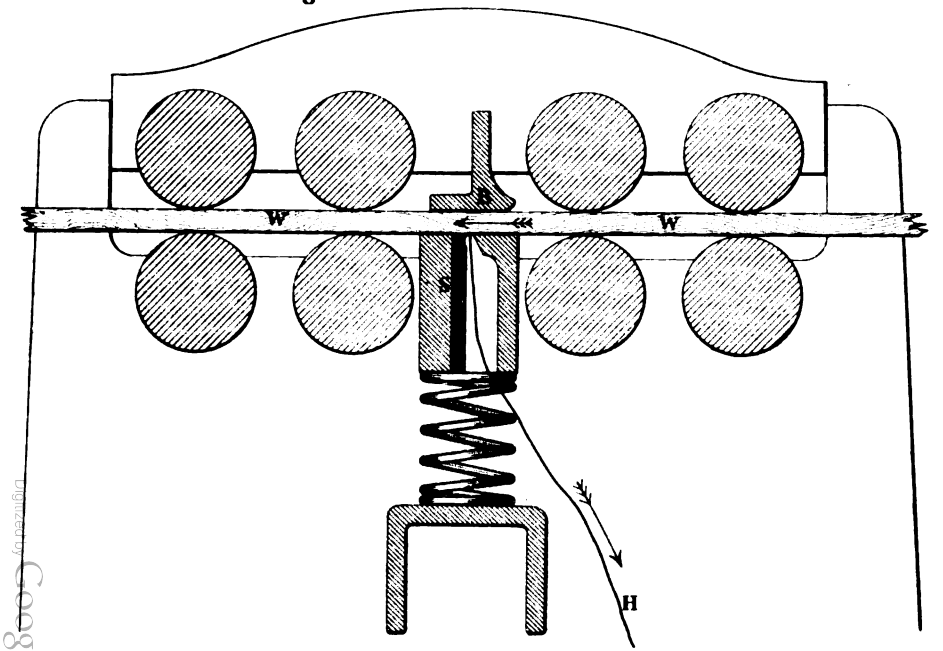
WOOD-CUTTING MACHINERY.

Plate 10.

Scraping Machine.

Fig. 52. *Sectional Elevation.*



(Proceedings Inst. M. E. 1885.)

Scale 1/8 th

0 5 10 15 20 25 30 Inches.

Scrapers. Full size.

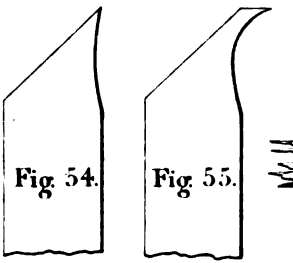
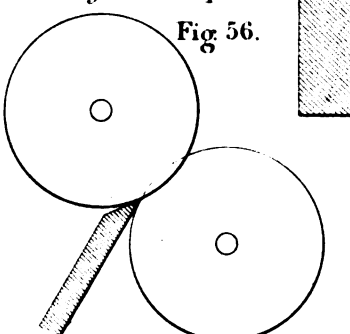


Fig. 54. Fig. 55.

Grinding of Scrapers.

Fig. 56.



Pressure-Bar and Scraper Block.

Fig. 53.

Scale 1/4 th

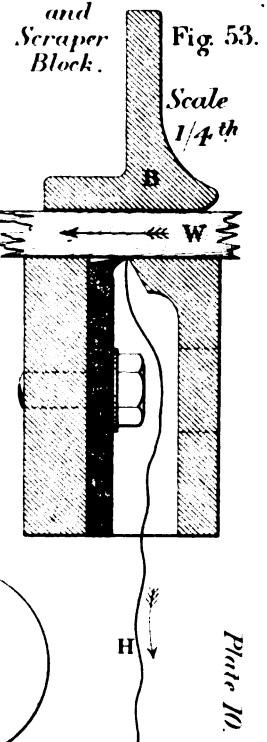


Plate 10.

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ON RECENT IMPROVEMENTS IN WOOD-CUTTING MACHINERY.

By Mr. GEORGE RICHARDS, of Manchester.

In bringing the subject of Wood-cutting Machinery before the Institution the author will not attempt to deal with more than a small portion of it, the object of the present paper being not to describe any particular machines, but rather to glance at some of the recent improvements in the details of their construction.

The many and various applications of machinery to finished productions in wood are exceedingly wide in character, and, as the writer ventures to think, larger in scope than the processes of metal cutting. In the latter the materials operated upon—iron, steel, cast-iron, and brass—do not vary much in general character; and the cutting tools act upon the materials at but slightly varying speed. The processes of turning, planing, shaping, slotting, and boring are almost analogous in the application of the cutting tools; the angles of the cutting edges, with the amount of clearance required, are almost constant; and the only matter affecting the size of tools is the quantity of material to be removed. In the same manner the various machine-tools used are the result rather of the sizes of the different pieces of work operated upon than of any difference in the application of the cutting tools themselves. By contrast, in the cutting of wood the materials to be dealt with are not only of various degrees of hardness—ranging from the softest pine to boxwood—but are composed of fibres of various natures, some dry as bone and others filled with sap, all of which require different treatment. To this complication in the material should be added the severing of the fibres both transversely and longitudinally by cutting edges of different forms, such as are used in sawing, planing, turning, boring, mortising, &c., the cutting

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speed ranging from 500 to 8000 ft. per minute, and the spindles and surfaces moving at correspondingly high speeds. All these conditions call for a wide range of construction in proportions of details and methods of lubrication; and should give to the production of wood-cutting machines a higher rank than it at present occupies in this country, and equal at least to that of machine-tool construction.

This contrast has been drawn in the hope that engineers may be led to investigate the general subject of this important class of machines, as it cannot fail to be of use in whatever class of manufactures they are interested. Compared with the papers and treatises on metal-cutting appliances, those on wood-cutting have been very few. In fact, the different books by Mr. J. Richards, the father of the writer, published some years ago, were the first which dealt with this subject.* Since those works were issued, it is but fair to say that their influence has been seen in many modifications of wood-cutting machines made in this country. About six or seven years ago, the importation of American wood-cutting machines was entered into by two firms, representing leading makers in America; and for a time American wood-cutting machines were met with everywhere in this country. The ingenuity of the details and their rapid working caused them to find favour; and they seem to have been more particularly designed to combine all the elements of easy and convenient manipulation. For this reason it was comparatively easy to get them adopted here, as they represented a new system of adapting wood-cutting machines to many purposes. They were not of the standard forms for doing rough work, but were for finishing processes, some of which had never been attempted here before. This importation could only continue for a time, as the machines, being constructed in a locality where labour and material were expensive, lacked the necessary weight and good workmanship to give them the wearing qualities required here. They were soon

* "A Treatise on the Construction and Operation of Wood-working Machinery;" "The Operator's Hand-book of Wood-working Machinery;" "Wood Conversion by Machinery."

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reproduced by makers in this country; and it is to be regretted that in some cases not only the ideas of the machines were copied, but the outlines and exact shapes of the parts. Altogether it is safe to assume that this influx of American ideas in wood-cutting machines was beneficial, as it led to a wider adaptation of machines to hand work, and gave an impetus to the manufacture of wood-cutting machinery in general, which makers of standard machines containing no important improvements could not readily have stimulated into activity. Some of the special features of these machines will be noticed later on.

Perhaps the closest relation of wood-cutting machines to engineering work is in their successful application to cheapening the cost of model or pattern making. This is a matter that should be of special interest to engineers, by whom patterns are generally considered mainly as an item of expense and in themselves of but slight value in comparison with their first cost. It is a common opinion among engineers that machines cannot be employed to much advantage in making patterns for castings, because of the irregularity of form and the constantly varying dimensions. This opinion is in a great measure correct, if only standard wood-cutting machines are considered, such as are intended for shaping uniform pieces. In pattern making, as in every kind of work, machines especially adapted for the purpose are required.

In order to form a correct opinion of how much machines can do in pattern making, there must be taken into account the extent of regular or plane surface required in patterns, and also of regular curved surface that can be turned in lathes or planed or sawn. In the building up of patterns, the component parts are to some extent regular, and the various pieces can be put together at a small cost. For example, in framing up patterns with segmental parts, glued or dowelled together, the planing of the surfaces and the sawing of the curves would form the largest item of expense. In the case of core-boxes in which the surfaces are not so well finished, and into which more wood enters than into the patterns, the adaptation of machines is unusually advantageous. In no other kinds of

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work however is there so much change and irregularity as in patterns, since in these there are rarely several pieces alike in shape or having uniform dimensions. Hence the first principle to be observed in arranging machines for model making is to provide for instant change from one operation to another; such changes must be made without loss of time, and without requiring skill on the part of the attendant. The machines have to be in common use, and must therefore be also strong and durable. Some samples of the class of work required in pattern making are exhibited for inspection. These pieces are just as they come direct from the machines, and are without any hand labour upon them. It will be noticed that the surfaces are exceedingly smooth, and, what is more important, are accurately square and true. Some attempts have been made to form an estimate of the comparative amount of saving by the use of machines; but, as can be readily imagined, the want of repetition of the work has hindered any correct data from being obtained. In a general way the results of comparisons in a number of cases where the writer has supplied the machines would seem to show that one pattern-maker out of every four could be readily dispensed with; or in other words 25 per cent. of the labour. In some of the larger classes of patterns this proportion would be greater, while in the smaller kinds of patterns it would be less. Assuming a pattern-maker's wages at from £80 to £90 per annum, a moderate investment in pattern tools, even where but few men are employed, would seem warranted.

Planing Machine. — The first machine to which attention is directed is the Planing Machine for preparing surfaces for glued joints free from "cross-wind," as it is generally termed. The principles of the cutting will be understood from Fig. 1, Plate 1. The cutter-block C revolves at a high speed, below the tables. The table A to the left, or behind the cutter, is exactly level with the circumference of the circle described by the cutting edges, while the table B to the right, in front of the cutter, is adjusted vertically to suit the depth of cut to be taken. The machine, though simple in detail, can perform a wide range of work, as

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pieces of any length and bulk can be faced by passing them over the cutter and tables. It will be noticed that as the front table B is lowered for different depths of cut the links L on which it is mounted cause the front edge of the table to keep equidistant from the cutter-block, their length being made equal to the sum of the cutter radius plus the clearance allowed. This is a matter of much importance in these machines, because the smaller the opening in the tables, the less danger is there to the workman, and the better is the work done. The guide or fence F on the table is used for squaring up the pieces by pressing a planed side against it, while the under surface of the wood W is being acted upon. The guide sets to any angle with the face of the table for chamfering or bevelling boards, in places where "draft" is wanted in the patterns. At a first glance it would be supposed that more force would be required than the workman commands to feed the wood over the cutters when a deep cut is being taken. This difficulty is met by an improved form of cutter-block used in all forms of rotary planing machines that are made by the writer's firm, the cutters being set askew, at a slight angle with the axis of the block, as shown in Figs. 2 and 3. The cutting is thus spread over a longer portion of the circle described by the cutters, instead of being all done at successive "chops." The action on the fibres of the wood is much easier, and smoother surfaces are produced. In Figs. 2 and 3 are shown cutter-blocks in which two and three cutters are used.

This machine has been extensively adopted, and is perhaps simpler and economises a larger proportion of labour than any other. It has proved an unfortunate machine in a great many cases; and the writer thinks it can claim to have mutilated the hands and fingers of the workmen more than any other in use. It is well known that the longer a machine is used by workmen the more careless do they become to the danger of being caught in the cutters. There have been many attempts to place guards over the machines; but unfortunately the guards have generally been removed by the workmen, and not used. No doubt this has been owing to the guard hindering the work. After trying several schemes, the writer has at last adopted a form of guard which seems

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to be all that can be desired, without inconveniencing the work. Figs. 4 and 5, Plate 1, show how this cutter guard is arranged on the machines. To the slide S, which moves across the table in front of the cutter, is attached a thin sheet-iron guard G reaching over the cutter-block to the back table. To the slide is connected a weight H, which draws the guard back to the fence F after the work has passed through; the guard then covers the cutter completely. In the case of planing a number of pieces of narrow width, the guard is clamped in position to expose only such a width of cutter as is in actual use, as shown in Fig. 5.

Dimension-Sawing Machine.—The machine shown in Plate 2 is next in importance in model-making, and is termed a Dimension-Sawing Machine. It bears the same relation to forming the pieces of the patterns that planing and shaping machines do to metal cutting. The surfaces produced are smooth, and ready for glass-papering, and are also square and true. The application of the machine is almost unlimited, as will be seen by the diagrams in Plate 4 of specimens sawn. Two saws are worked in the machine, one for slitting and one for cross-cutting; and both are elevated through the table as desired by rotating the frame in which their spindles are mounted. Figs. 8 and 9, Plate 3, show how the spindles are driven by one belt from a counterbalanced pulley P below, as they are altered in their relative position with the table. The table top of the machine consists of a stationary part A, Fig. 7, and a part B sliding on accurate ways. The wood is guided by fences fitted with great care. The saws themselves deserve some notice, and are shown in section in Fig. 10. A slight "set" is given to the teeth, but the clearance proper is due to the sides being formed concave in the operation of grinding. The various sections shown in Plate 4 are produced by the vertical movement of the saw through the table, and the cross movement of the fence. For example, in cutting out a core-box the small grooves are cut through to remove the bulk of the wood, and at the same time the saw leaves a gauge-line through the box, to which the workman works with his chisel. Another class of useful work is in halving pieces together, in which

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both the cross-cut saw and a slitting saw are necessary. In like manner nearly all of the various mitres, squares, and bevelled pieces can be produced; depending mainly on the ingenuity of the workman.

To produce the smooth surfaces on the samples, it is of course necessary that the teeth of the saws should have a uniform set; and for enabling users of the machines to keep the saws in this condition, the writer has recently schemed the little device shown in Figs. 11 to 13, Plate 3. The saw rests on a conical bush B, Fig. 11, which can be adjusted to bring the saw level on the hardened steel die D. This die has a bevelled edge turned eccentric, Figs. 12 and 13, so as to be of varying width for larger or smaller teeth. The set is obtained by blows from an ordinary hammer. In some cases for larger saws the pressure to set the teeth over is given by a steel hammer A pivoted to strike on the teeth when itself struck by a hand-hammer H, as shown in Fig. 11.

Band-Sawing Machine.—The Band-Sawing Machine, Plate 5, is better known in pattern shops than those already described; but the difficulty of the saw-blades breaking has greatly retarded its extensive use. For a long time the breaking of the blades was regarded as unavoidable; but experience has fully demonstrated that with proper details in the construction of the machines the breaking of blades is the exception rather than the rule. The wheels when rotated at a high velocity acquire considerable momentum, and the resistance to the saw blade in cutting causes the top wheel to over-run the bottom or driving wheel; the top wheel thus winds itself downwards along the rising side of the saw, thereby depressing the springs on which its bearings are carried and by which the proper tension is put upon the saw; and it thus allows the saw to bend in its course from the top wheel down to the wood, thereby easily breaking it, as illustrated at K in Fig. 29. To overcome this important objection, a lighter top wheel was necessary, and in Figs. 29 to 31 is shown a wheel made by the writer, with which up to the present time not a single saw has been broken on these machines; a 36-inch wheel is shown. It will be seen that this wheel resembles an ordinary bicycle wheel, except that

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the proportions are heavier, and that the rim is flat in section, Fig. 31, and of suitable width for the saw to run on. The wheel is perfectly balanced, and the construction admits of the weight being reduced to a minimum. A 30-inch wheel weighs only 15 lbs., and a 36-inch wheel 25 lbs., and others are in like proportion. In comparison with the old cast-iron wheels, in which the weight varied from ¾ to 1½ cwt., the good results in saving the saws will be apparent. Both the top and the bottom wheels are covered with rubber of a special quality, Fig. 31, to make an elastic cushion for the saw.

Next after the wheels comes the method of supporting the blade above and below the wood while sawing, which will be readily understood from Fig. 32, Plate 6. The guides GG, Fig. 32, are clearly shown in Figs. 33 to 36. A hardened steel pin P is placed at the back of the saw S, and can be turned round to present new wearing surfaces as required. Thin strips of apple wood A soaked in oil are placed at each side of the saw, one or more being brought to bear against the saw according to its width. The top guide G, Fig. 29, should always be close down to the upper surface of the wood; and in order to ensure the workman adjusting this guide, it is counterbalanced and readily moved up and down and clamped in any position.

In addition to these details, another small attachment has something to do with preventing the saws from breaking—namely a chip guard, which is placed just where the saw runs on to the lower wheel. By its peculiar shape it turns to one side any small pieces of wood which may have worked through the slot in the table.

It is not necessary to enter into any detailed description of general machines used in pattern-making, such as circular-saw benches, lathes, jig saws, &c.; although they are of course as indispensable as the machines here described, no special improvements have been made in them for some years past.

Sharpening of Cutters.—Apart from the importance of properly constructing the details of wood-cutting machines, the keeping of the cutting edges in good condition, both as to sharpness and as to quality of temper, is one of the elements necessary to produce

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economical results. In the case of saws, it is needful to have appliances for keeping the teeth of correct shape, and of the proper depth, and with the proper amount of set. Machines for this class of work are constructed by various makers, and mostly of one pattern, which experience has no doubt determined as being the best. The sharpening of the cutters for planing machines is equally important; but in the method of adapting machines to the grinding of the edges various systems have been tried. In Fig. 45, Plate 8, is shown a diagram of the most general application of emery wheels to the grinding of bevel edges on the cutters; this system of grinding had continued in use for some years before it was departed from in the system shown in Fig. 46. In the former, Fig. 45, a wheel was used of sufficiently large diameter that the surface produced on the bevel of the cutters by the circumference of the wheel should be but very little concave or hollow; in practice it was found that as the wheel was reduced in diameter the concavity was increased to such an extent as to leave insufficient material at the back of the cutting edge for supporting it properly and carrying away the heat generated. No doubt for this reason the later plan in Fig. 46 was brought forward for producing a flat surface on the bevel of the cutter; the gradual wear of the flat annular face of the grinding wheel does not in this case affect the uniform flatness of bevel of the cutting edge. Both of these systems are open to very grave objections; and in fact any mode of grinding based on this arrangement of the wheel and material must present a difficulty in obtaining good results. It will be seen from a glance at these two diagrams that the contact of the surface of the grinding wheel with the cutter is represented by an area equal to the breadth of the bevel multiplied by the width of the grinding face; therefore each particle of metal and of stone or emery that is separated in grinding must pass for a short distance between the wheel and the cutter. However small such a particle may be, it is impossible for it to be carried away without first being pressed between the two surfaces; and as the emery wheel is more porous than the metal, the small particles get embedded in the wheel. From a large experience in the process of grinding, the writer believes that any mode of grinding according

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to either of these plans must result either in only a small amount of metal being ground away, or else in constant difficulty in keeping the grinding wheels in condition for acting.

In Figs. 37 to 44, Plates 7 and 8, is shown a new machine recently brought out by the writer's firm for grinding cutters. The grinding wheel G has a transverse movement given to it, equal to two-thirds of the breadth of its face, so as to bring every part of its face over the work; by this plan its face is kept straight, as shown in Fig. 44, its contact with the cutter C being only a straight line across the bevel of the cutter. The lateral movement of the wheel is obtained by giving the driving shaft itself a reciprocating motion endways through its bearings, by means of a crank-pin P on a worm-wheel actuated from the driving shaft D, Fig. 42. The pressure of the wheel on the cutter is regulated by gravity, by adjusting the counterweight W, as shown in the side view, Fig. 37. As the cutter C is traversed from end to end beneath the wheel G, Fig. 37, the grinding continues until the wheel comes to the limit of the adjustable stop S in its downward movement; so that in the case of small "nicks" in the edge of the cutter, the machine can be set in operation and the grinding continued at a uniform rate, until the "nick" is ground out. The result of experience with the grinding wheel acting in this way under a number of conditions proves that the particles of steel ground off the cutter get away so freely that no heat is generated in the grinding. In practice this means that the cutting edges themselves are left with their original temper, and will work for a much longer time without the necessity for re-sharpening. The longitudinal traversing movement of the table is obtained by a very simple frictional reverse movement. In Figs. 41 and 43, Plate 8, are shown the friction wheels FF, which are locked in either of the two positions shown in Figs. 38 and 39, Plate 7, by means of the points J, Fig. 37, the reversing lever L being worked by the tappets TT on the sliding table of the machine. For throwing both friction wheels out of gear, a double-notched block B, Fig. 37, is inserted by hand between the locking points J. In Fig. 40 is shown the manner in which the sliding table is moved by a steel-wire cord R wound half a turn round each of two small

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drums on the friction-wheel shaft A; this dispenses with rack and pinion, and the practice is found to give very smooth motion and excellent results. It will also be seen that, as the cord makes no more than half a turn round either drum, it has no tendency to lead sideways, as it would have if it made one or more whole turns round one of the drums.

It will not be out of place to note here that the rapid development of transmission by wire cords in many branches of engineering should receive some attention in designing machines which have reciprocating parts of inconsiderable weight. In several instances wire cords have been applied by the writer's firm with much success for moving the platens of special machines.

Mention has been made of improved details introduced into this country by American makers; and a few of these will now be noticed.

Panel-Planing Machine.—In planing wood to a parallel thickness, it is fed through what are known as Surface or Panel-Planing Machines. The uniformity in thickness is obtained by the use of a revolving cutter-head above the wood, and a fixed table beneath, as shown in Fig. 47, Plate 9. The wood may not be true on its surface either before or after passing through the machine, but its cross-section at all points in its length has the same thickness. Formerly the wood was held down by the feeding rollers; but in recent practice auxiliary holding-down parts are used, termed pressure-bars. Referring to Figs. 48 to 51, which show larger sections of the cutter-block and feeding mechanism, C is the cutter-block, W the wood, F the fluted feeding roller, D the delivery roller, while P and B are the pressure-bars. The bar P on the front or feeding side of the machine has sufficient adjustment for various thicknesses of the roughly sawn board; while the back pressure-bar B requires no adjustment, except the elastic pressure of a spring S to keep the wood down. The front pressure-bar P has attached to its ends a pair of yokes Y, which are fitted to slide in circular grooves outside the cutter-block bearings and concentric with them. The back pressure-bar B also has similar attachments, and slides at each end in a circular

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groove concentric with the cutter-block. In this way each pressure-bar is maintained at a uniform radial distance from the axis of the cutter-block, while each is allowed a slight extent of movement circumferentially. By the use of these pressure-bars, thin pieces are more readily planed, while thicker pieces are held more firmly against the table. Another feature of equal importance is the action of the pressure-bar spring J in breaking off the splinters and preventing their tearing out. The application of such pressure-bars to surface-planing machines has now been generally adopted by English makers, and has led to much better results as to both the quantity and the quality of the work.

Scraping Machine.—In conjunction with this system of planing, reference will now be made to a machine for Scraping the planed surfaces by mechanical means, instead of the laborious hand method. It may safely be considered the most important machine operating on wood that has been brought into use for many years past. It was developed and successfully carried out by Baxter D. Whitney at Winchenden, Massachusetts, as the result of continued experiment, and represents perhaps one of the most difficult problems ever attempted in cutting wood. The difficulties of bringing the positive mechanism to perform the work formerly done by hand only will be self-evident.

The scraping machine, shown in section in Fig. 52, Plate 10, resembles the panel-planing machine, but has more feeding rollers; and instead of a rotary cutter above the wood, a fixed tool S is placed beneath, the wood W being held down by the pressure-bar B above it, as shown to a larger scale in Fig. 53. The tool is similar to the hand-scraper, and is carefully prepared by a special grinding machine constructed for the purpose. The wood is fed at the rate of 40 feet a minute, and a wide thin shaving H is taken from the entire surface.

The cutting-edge of the scraper is shown full size in Figs. 54 and 55. It projects about one-thousandth of an inch above the surface of the holding block; and the amount of this projection determines the thickness of the shaving. In preparing the cutters or scrapers, two small emery wheels act on the front and back, as shown in Fig. 56,

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Plate 10, until a true surface is obtained. A burnishing tool then turns over the small lip or burr to form the cutting-edge. These machines have been adopted by most railways and shipbuilding yards for finishing panels; and it is expected that their application to other branches of manufacture will be only a matter of time.

The machines that have here been described belong to what is known as the finishing class of machines; that is, machines for dispensing with skilled manual labour. In what are known as breaking-down machines for doing the rough work, there has not been for years past in this country much room for improvement. It is natural that the finishing class of machines should have been developed in America sooner than here, owing to the difficulty there experienced in obtaining skilled hand-labour and to its high price; and the rapid manner in which these improvements have made their way in this country shows that very little prejudice has been exhibited in adopting foreign ideas.

Discussion.

Mr. M. Powis Bale agreed with the opening statements in the paper as to the many difficulties to be overcome in wood-cutting machinery. The varying nature and conditions of the wood rendered it necessary that the shape of the saw teeth, the cutting angles, and the speeds, should be different for almost every kind of wood. Although the improvements mentioned in the paper were confined to the machines manufactured by the author, many other machines had also been latterly introduced, which were well worthy of a short notice. For instance, there was Worssam's board cutter, and Ransome's cask-making machinery; and also Tighe Hamilton's dove-tailer, in which the saw was made drunken or wobbling, and in combination with its rotary motion had also a horizontal

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(Mr. M. Powis Bale.)

reciprocating motion which cut the dove-tail.* Then again there was the planing machine of Chapman, made by Hewetson, which would plane thin boards on one side at the rate of 250 feet a minute; and its side cutter spindles ran faster probably than in any other machine made, their speed being something like 7,500 revolutions a minute; the spindles were of steel, and their bearings, probably about four diameters long, were of phosphor-bronze. The machines described in the paper were no doubt good of their kind; but as they had been spoken of as of American origin, it might be as well to say that several of their features were essentially English. The cast-iron box-framing for instance was essentially English, so much so that for some years after it had been introduced in England the American makers had still adhered to wood framing, for the alleged reason that wood absorbed the vibrations much better than iron; but the fallacy of that view had been proved by the subsequent universal adoption of the cast-iron box-framing. Many years ago Mr. H. Wilson, the inventor of box-framing and the manager of the firm with which he was formerly connected, had had to pay as much as £22 a ton for those very box-framings, which could now be purchased at £8 or £9 a ton.

The cutter-block represented in Fig. 2, in which the cutters were put on askew, was not new by any means; the same principle, only carried to a further extent, had been used in France for many years, and was seen in the Paris Exhibition of 1878, where the cutters of Godeau were exhibited, arranged spirally round the cutter-block so as to give a shearing cut to the wood. Those spiral cutters were very good in theory, but it was difficult to keep them sharp. They were still in use in France, he believed, but they had not been introduced into this country.

The arrangement for setting the teeth of circular saws, described in page 83 of the paper, had been used by himself also for years; and a similar arrangement would be found described in a book on saw mills which he had published some years back.

Referring to the band-saw, there was no doubt that light wheels were of very great importance; but the reasons mentioned for

* *See* Proceedings, 1868, page 81.

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band-saws breaking were not the only ones. For instance, there was the expansion and contraction of the saw; when in use the saw got very hot and expanded, and the wheels were therefore tightened up by the handscrews for keeping it taut. When the work was finished, the blade cooled down and contracted; and unless the wheels were then slacked back, it often ended in breakage, especially with the saws having angular teeth. If the saw teeth were rounded in the gullet, there was rather less likelihood of their breaking. Another reason for band-saws breaking was that they had to bend too sharp round the wheels, in consequence of the wheels being made too small; but the small wheels were gradually giving way to larger ones.

Mr. THOMAS N. ROBINSON thought all would agree with one statement made in the paper, that the use of machines in pattern-making was very advisable wherever they could be adopted; and there was no doubt the machines described in the paper were very useful for that purpose. One of the most serviceable of these he thought was the hand-feed planing machine; but there were one or two points in its construction which he did not quite agree with. In the first place, the tables of the machine—the parts which supported the timber—ought in his opinion to be as rigid as possible. In the machine here described they appeared to be carried on links: which he thought was not a very rigid support. Seeing that the tables required to rise and fall through only a slight distance—the back one only sufficient for adjustment, and the front one only enough for determining the depth of the cut—the advantage obtained with the radial links, of keeping as narrow as possible the opening between the tables when raised or lowered, could be obtained almost as well by mounting the tables on inclined slides, sloping downwards from the cutter-block at an inclination of about 25° to the horizontal, so that the small movement of the table edges would be almost tangential to the circle described by the revolving cutters; a firm support would thereby be obtained for the tables. Again with regard to the skew cutter-block, it was a very good block for cutting, as it relieved the cutters to a very great extent; but

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(Mr. Thomas N. Robinson.)

for very accurate work for jointing he did not think it could be quite recommended, if straight-edged cutters were used, because a straight-edged cutter, if set slightly askew upon the cutter-block, would not cut the board perfectly level, but would leave it slightly rounded transversely. If the skew cutter-block was wanted to cut perfectly true, the cutters should be ground slightly curved on the edge, or else a true helical cutting edge should be used, so that the edge of the cutters should be all along equidistant from the axis on which the cutter-block revolved. The cutter-block with true helical cutters was used a great deal in tenoning machines, and machines which cut across the grain of the timber.

A good deal of attention was now being paid to the use of fixed knives in planing timber. That mode of cutting timber was very well adapted for rapid work. It had for some long time been largely used in conjunction with rotary cutters for planing floor-boards. These were now planed on the continent at a speed of something like 120 feet run per minute, being planed simultaneously on all four sides at that speed, and at the same time tongued and grooved. A small machine, which was much used for planing rough spruce for making small packing boxes, worked with a fixed knife at the rate of 500 feet run per minute. It shot the board over the knife, and acted just like an ordinary hand-plane.

It was stated in the paper that very little improvement or progress had been made in the class of machines known as machines for breaking-down timber; but that was hardly the case. A machine now very largely used in this country for breaking-down hard woods like ash and oak, and other rough English timber, was the horizontal form of reciprocating saw, which would cut at a very high speed. The roughest shaped timber could be very easily fixed on the table of the machine, and the boards cut off could be very easily varied from $\frac{1}{8}$ inch thick up to 7 or 8 inches thick, or the log could even be halved by cutting it through the centre. The saws ran at a very high speed, travelling at about 1500 feet a minute; and they would cut in both directions with a continuous feed. This was found to be a very useful machine for converting timber at once from the rough log for almost any purpose.

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Mr. F. W. CROHN mentioned as a matter of historical interest that cutter-blocks having the cutters placed askew for planing machines had been made at the Usine de Gravenstaden near Strasburg more than thirty years ago.

Mr. FREDERICK COLYER also remembered the skew cutters being used in England about thirty-two to thirty-three years ago.

Mr. WILLIAM SCHÖNHEYDER asked how the knives for skew planing were ground; because it seemed that if they were ground in the machine shown in Plate 7 their edge would be straight, and the board cut by them would be rounded. For planing true, the knives would require to be ground to a curve; but he did not know exactly what curve it would be.

Perhaps the author would also say how the burr was put upon the scraper. It was said (page 89) to be put upon it by a burnishing tool; but as the scraping knives were ground to a sharp edge, it was evident that the burnishing tool must be guided in some way so as to get a perfectly straight scraping edge. He wished to ask whether that was done by machine or by hand.

Mr. THOMAS N. ROBINSON said of course the skew cutters could be ground slightly round by hand; but that was not a very certain process. To do accurate work in the way of jointing, the cutters ought to be shaped true with absolute certainty; otherwise it was more or less guess work. By using a helical cutter, which was bent as it were round the cutter-block, a true cutter was obtained although the edge might be ground straight.

The burred edge for the scraping tool was put on by passing the tool under a steel die, by which the edge of the cutter was slightly turned over after it had been ground.

The PRESIDENT said that, whatever conclusion might be arrived at as to the novelty or otherwise of some of the machines described, those present would admit that they had listened to a very useful paper and discussion. However conversant some of the members

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(The President.)

might be with such matters, the majority of them probably had not made a special study of the subject, and they were therefore benefitted by having presented to them the latest information as to wood-cutting machinery. Almost every mechanical engineer in the early part of his career had been occupied in pattern making, and therefore felt interested in work of a kind which he had himself laboriously performed with calipers, compasses, gouges, chisels, planes, and so forth. It was interesting to see that all such work was now capable of being not only done by machinery, but also done much more accurately and more quickly than by hand. It seemed to him that the application of this kind of machinery extended far beyond pattern making. Shipbuilding was one of the trades in which there was an immense amount of wood work in fittings, for cabins and other parts of the ship; and in its production machinery of this kind must be very useful. Then there was cabinet making and house building; and in fact wherever wood was worked up at all into finished forms this kind of machinery must be of service. One machine which struck him as being especially remarkable was the scraping machine. That the shavings exhibited from it were simply produced by the burred edge of a scraper appeared very wonderful; as also that the scraper, which had always seemed rather a crude tool, likely to be superseded altogether, should have developed into a very important tool in wood cutting.

He proposed a vote of thanks to Mr. Richards for his valuable paper, and regretted that he was not present.

Mr. RICHARDS, greatly disappointed that through an accidental circumstance he was not present at the meeting, as he fully intended to be, has since sent the following observations upon the remarks made in the discussion:—

He would have been glad to introduce into the paper some reference to other wood-cutting machines, if they had come under his notice. The machines referred to by Mr. Bale must certainly be regarded as special machines, having not so general an application as those described in the paper.

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With reference to the skew cutters, the principle upon which they work has not been brought forward as new, as it is well known and has been described on various occasions previously. The recent improvement, if any, consists rather in reducing the amount of the angle at which the cutters are set oblique, so that their cutting edges can practically be ground straight, and yet will not produce a convex surface on the wood. In practice for example in a cutter-block 12 inches long the cutter is set $\frac{1}{4}$ inch askew, and in a cutter-block 30 inches long about $\frac{3}{8}$ inch. Taking the versed-sine of an arc of $\frac{3}{8}$ inch length in a circle of 6 inches diameter, which would represent the amount of skew given to the cutters, it will readily be seen that the amount of curvature given by the straight cutters to the surface of the wood is really of no importance in practice. Although skew cutters have been known for many years, their direct application is believed by the author to date from their introduction from America about seven or eight years ago, when they were first introduced on surface-planing machines. The action of skew cutters is most familiar in tenoning-machine cutter-blocks, which have from the first been constructed with the cutters set considerably askew. In this case they are ground with a curved edge; and from the nature of their action—cutting in a direction coinciding with the fibres of the wood—no other form would answer.

The fixed-knife planing-machine mentioned by Mr. Robinson is certainly a novel machine for planing what are known as lap boards and other boards used in small packing boxes, the wood being fed by a large roller covered with rubber. It has received the author's special attention, but he has gathered the impression that in practice the cost of the rubber roller, and its liability to be spoiled by the wood catching in the cutters, place it at present in the category of experimental rather than of practically successful machines.

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DESCRIPTION OF THE TOWER SPHERICAL ENGINE.

BY MR. R. HAMMERSLEY HEENAN, OF MANCHESTER.

The Spherical Engine consists, as its name betokens, of a system of parts contained within a sphere, and so united as to enable them under the action of steam pressure to impart rotary motion to a shaft. It is an engine that seems peculiarly suitable for high-speed direct driving. It is shown in Plates 11 and 12, in front elevation and plan; and is the invention of Mr. Beauchamp Tower, to whom the idea of its construction originally occurred through watching the relative motions of the three parts composing a universal joint. The geometrical principles of these motions will accordingly be briefly considered first, before describing the actual mechanism by which they are practically carried out.

Geometrical Construction.—Considered geometrically, as illustrated in Plate 18, the three elementary moving parts of which the engine is composed are—a pair of quarter spheres A and B, with a circular disc P of infinitesimal thickness interposed between them, the diameter of the disc being the same as that of the sphere of which they are sectors. The straight edges of the sectors are hinged on opposite sides of the disc along diameters at right angles to each other, as illustrated in the diagram, Fig. 35, Plate 18, in which the disc P, being seen edgeways, appears as a straight line only. Each sector rotates upon an axis of its own, upon which it is fixed symmetrically; the two axes lie in the same plane, which is the plane of the paper in Fig. 35; and they meet in the centre of the disc P at an angle of 135 degrees. The two sectors A and B thus correspond with the two bows of an ordinary universal joint; and the disc P answers to the crosspiece connecting the bows.

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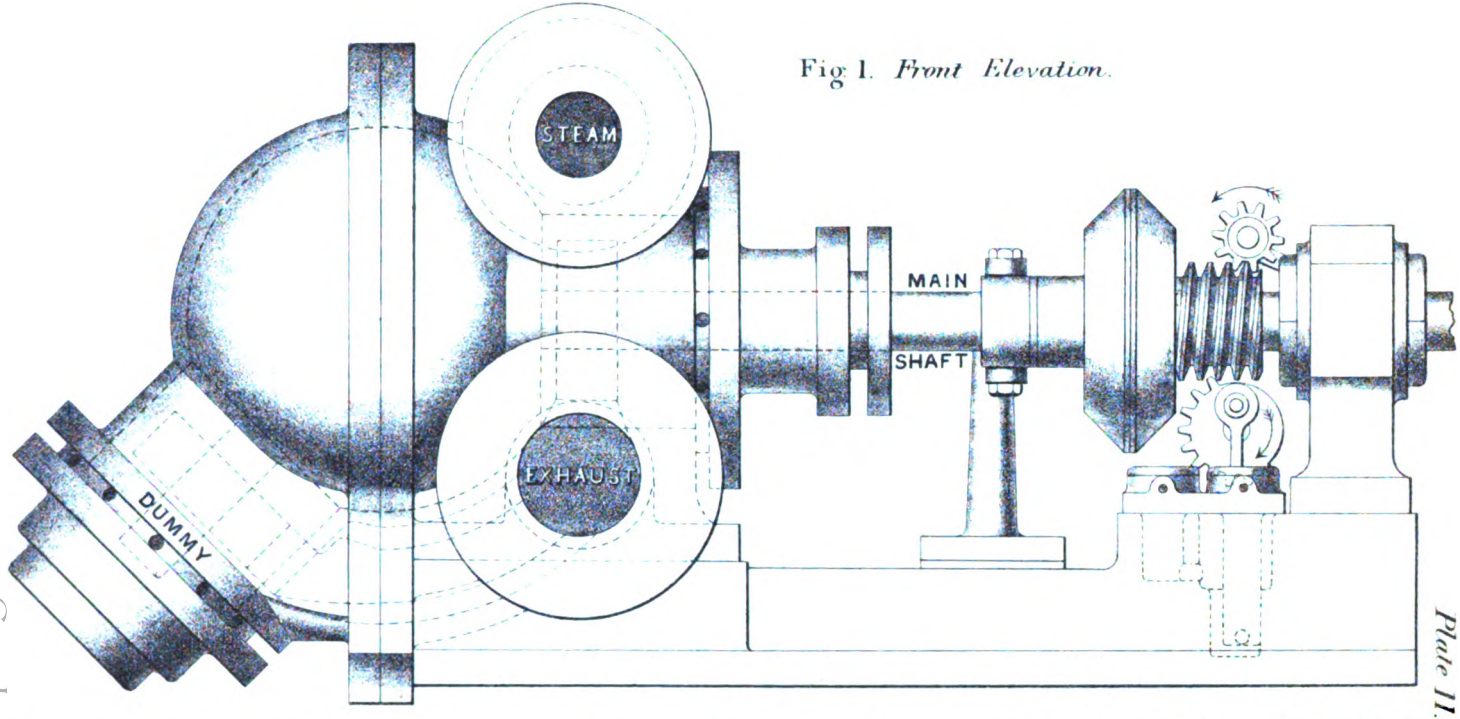
SPHERICAL ENGINE.

Plate II.

Fig 1. *Front Elevation.*



0 3 6 9 12 Inches.

Scale 1/4th

(Proceedings Inst. M.E. 1885.)

Plate II.

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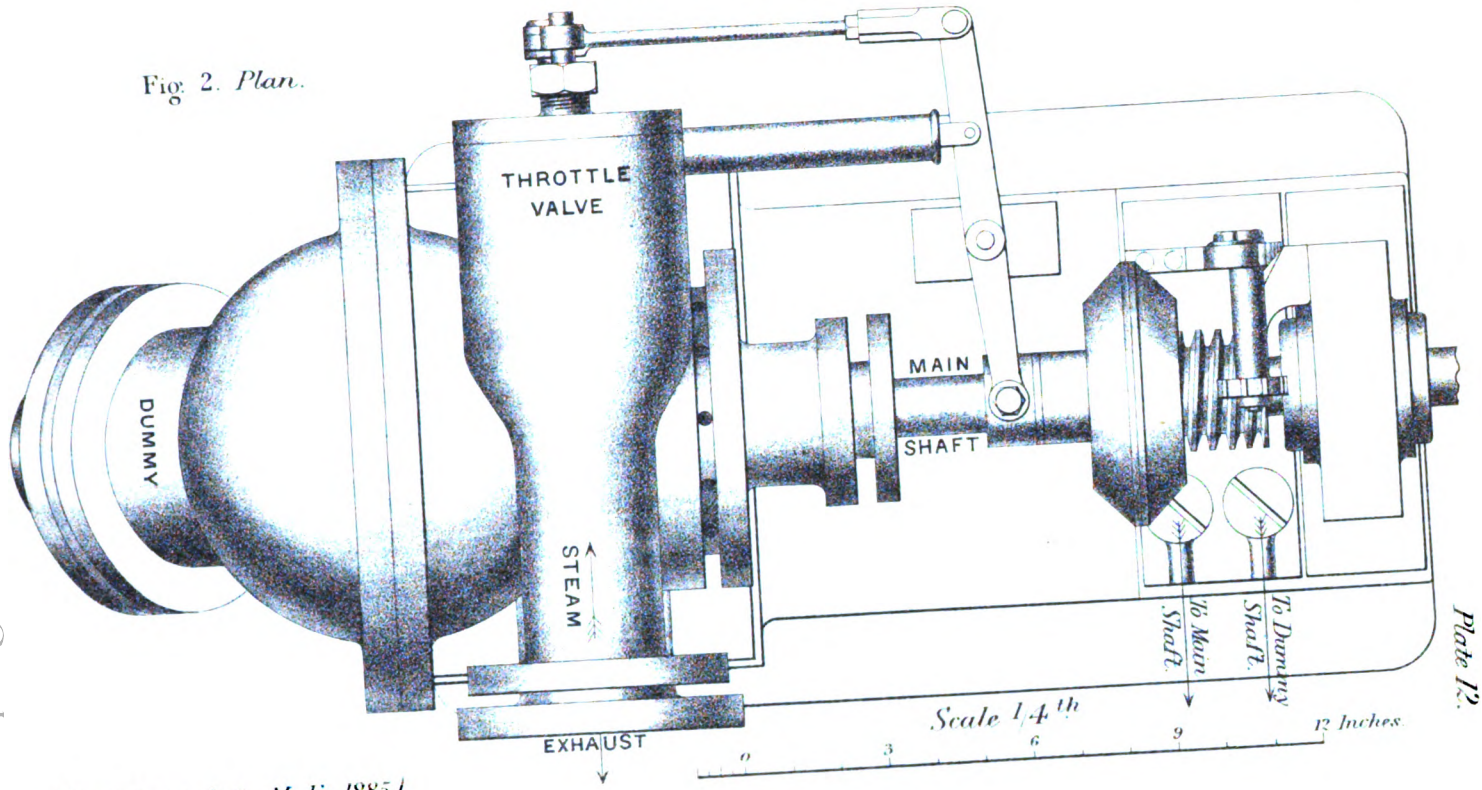
SPHERICAL ENGINE.

Fig. 2. *Plan.*



(Proceedings Inst M. E. 1885.)

Plate 12.

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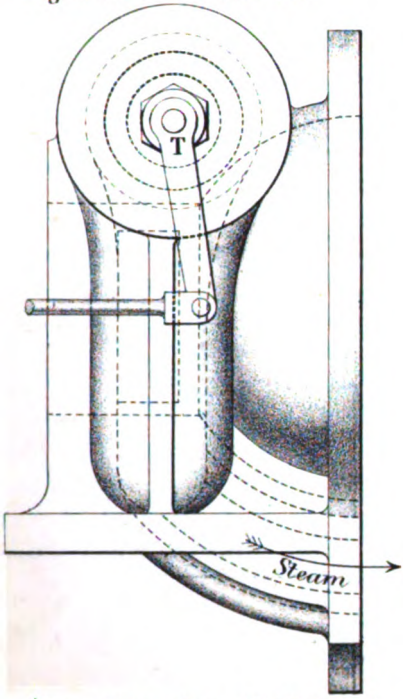
SPHERICAL ENGINE.

Plate 13.

Fig. 4. *Back Elevation.*



Main Half of Casing.

Fig. 3.

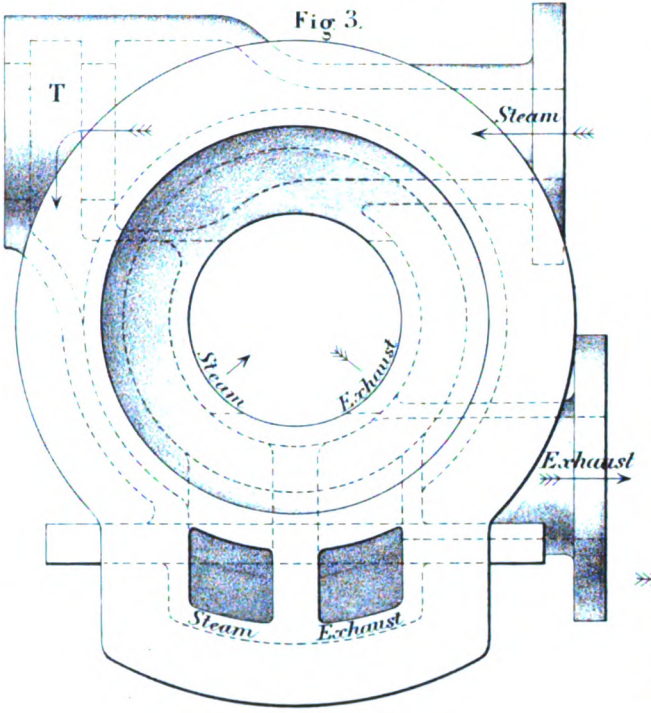
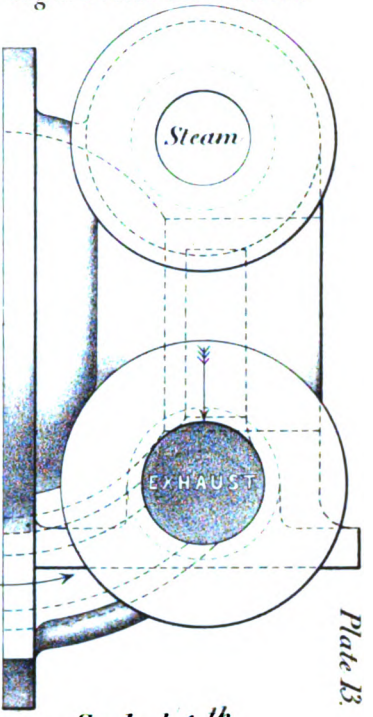


Fig. 5. *Front Elevation.*



(Proceedings Inst. M. E. 1885.)

Scale 1/4 th

Plate 13.

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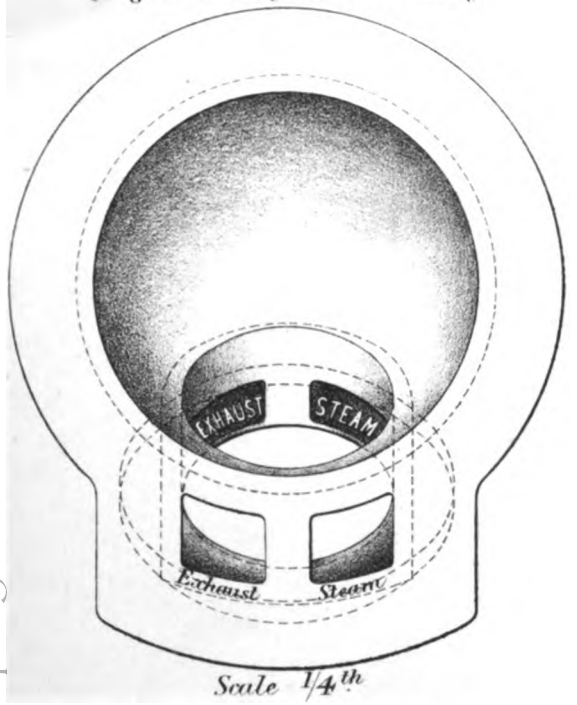
SPHERICAL ENGINE.

Plate 14.

Fig. 6. *Dummy Half of Casing.*



Scale 1/4th

(Proceedings Inst. M.E. 1885.)

Fig. 7. *Combined View of Piston and Blades.*

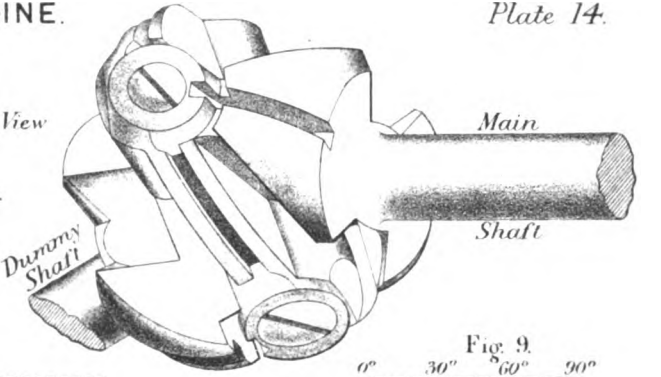


Fig. 8.

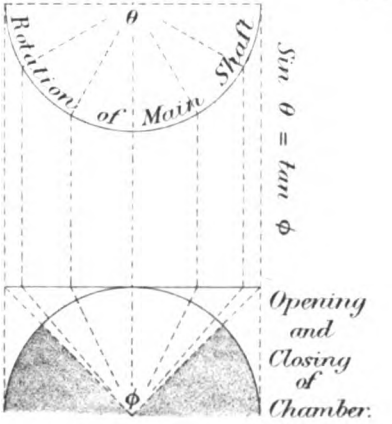


Fig. 9.

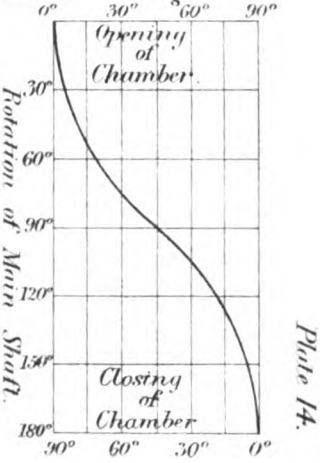


Plate 14.

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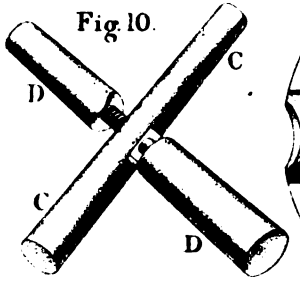
SPHERICAL ENGINE.

Plate 15.

Hingeing.

Fig. 10.



Piston.

Fig. 12.

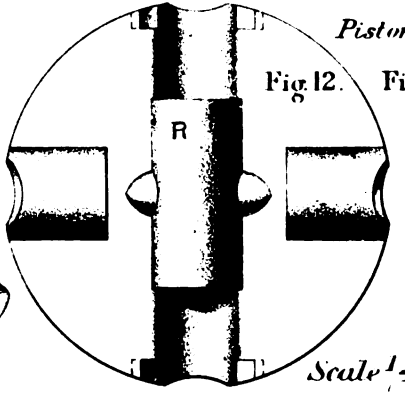
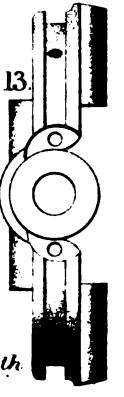
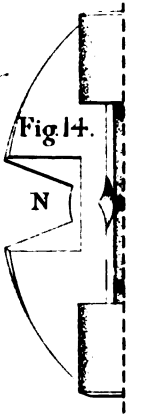


Fig. 13.



Scale 1/4th

Fig. 14.



Blade.

Fig. 15.

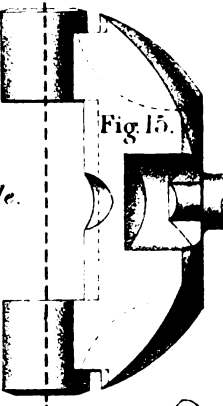


Fig. 16.

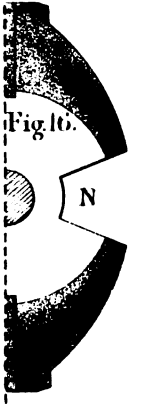


Fig. 11.

Piston.

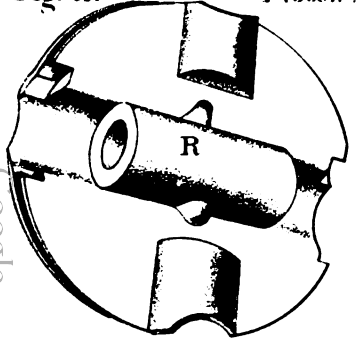


Fig. 18.

Blade.

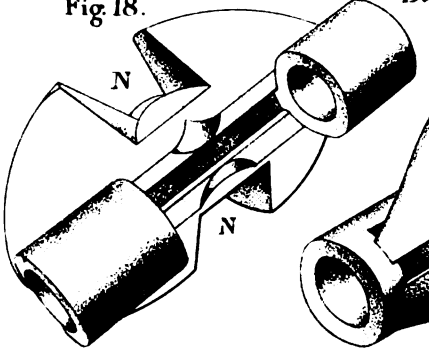


Fig. 19.

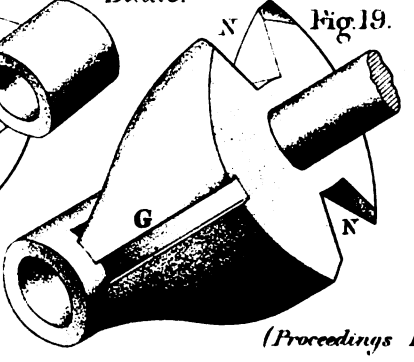


Fig. 17.

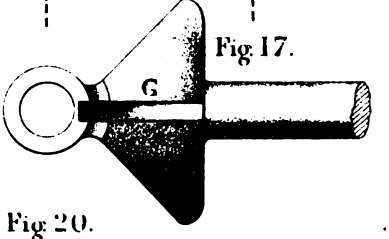


Fig. 20.

Thimble.

Fig. 21.

(Proceedings Inst. M. E. 1885.) Scale 1/4th

Plate 15.

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SPHERICAL ENGINE.

Fig. 22. *Main Half of Casing.*

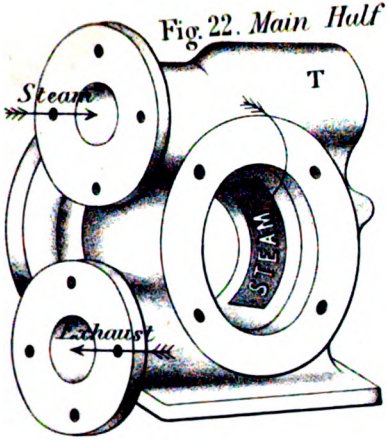
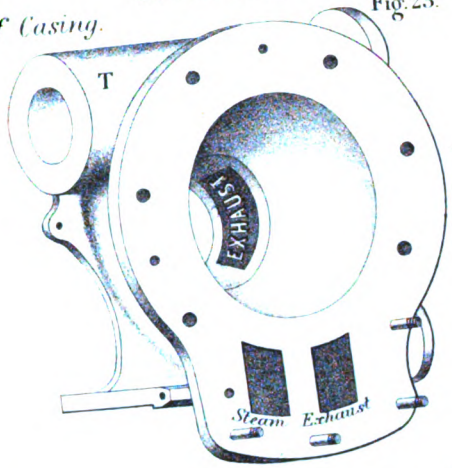


Fig. 23.



Valve Faces.

Fig. 24.

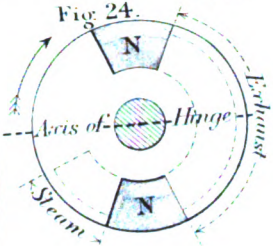
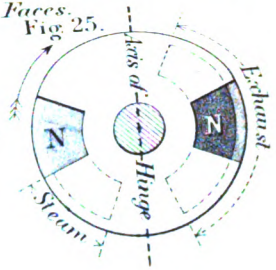


Fig. 25.



Valve-Blocks and Bearings.

Fig. 26.

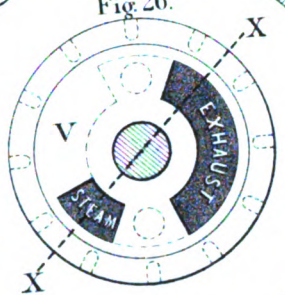


Fig. 28.

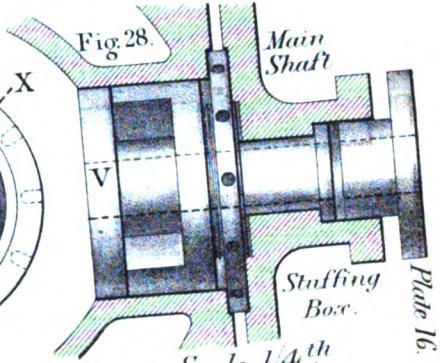
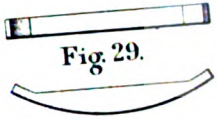


Plate 16.

Piston Packing.

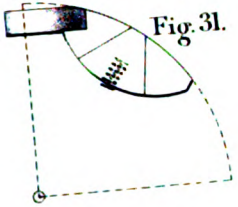
Fig. 30.

Fig. 29.



Blade Packing.

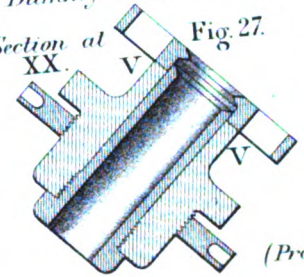
Fig. 31.



Dummy Shaft Bearing.

Section at XX.

Fig. 27.



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SPHERICAL ENGINE.

Oil Pump.

Plate 17.

Fig. 32. *Back Elevation.*

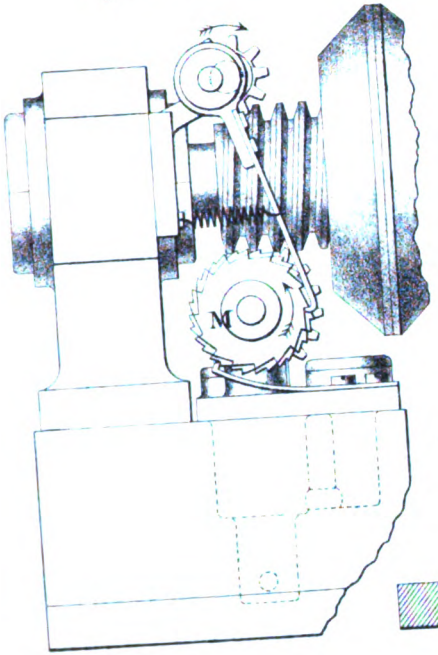

Fig. 33. *Transverse Section.*

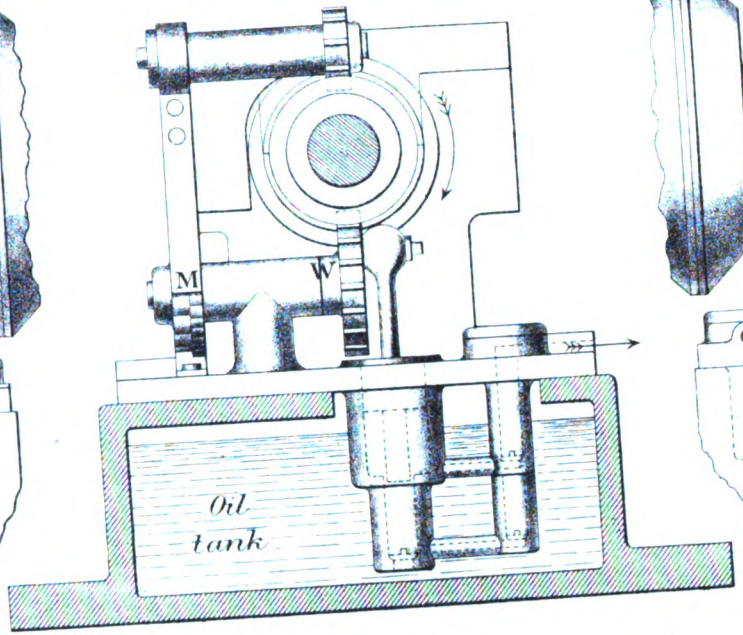

Fig. 34. *Front Elevation.*

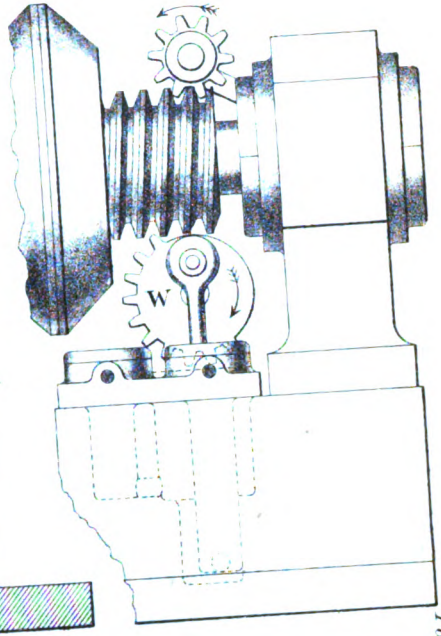

Plate 17.

10 Inches

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SPHERICAL ENGINE.

Geometrical Construction.

Fig. 35.

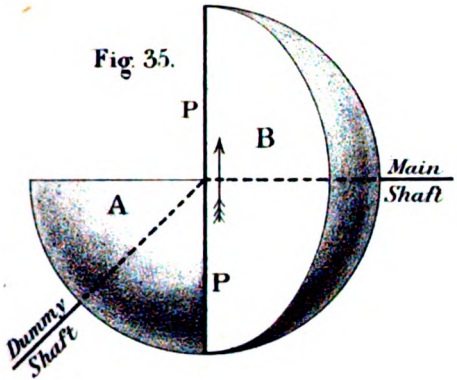

Fig. 36.

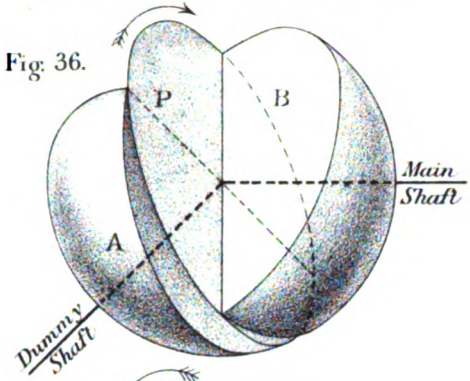

Fig. 37.

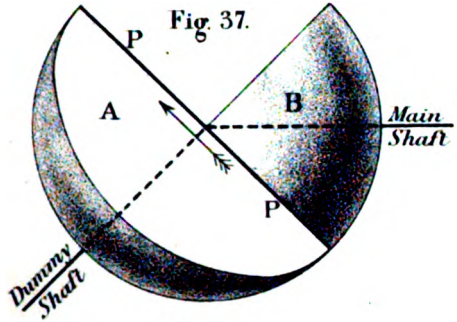

Fig. 38.

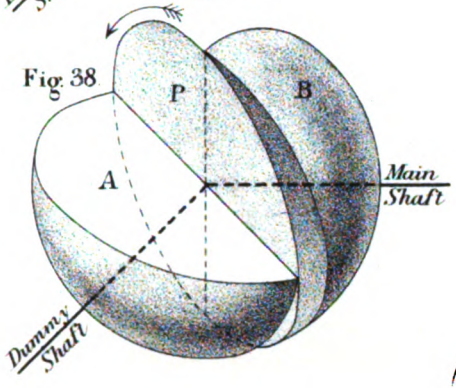

Fig. 39.

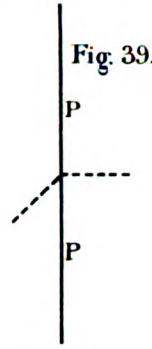

Fig. 40.

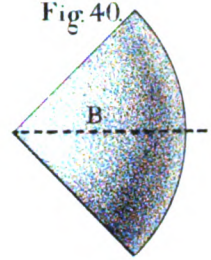

Fig. 41.

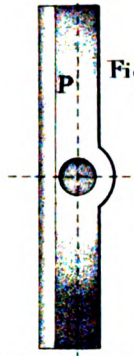

Fig. 42.

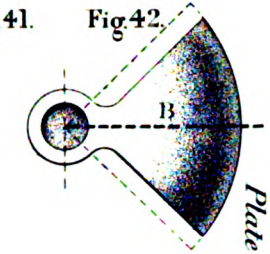

Plate 18.

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Starting from the position shown in Fig. 35, and supposing the direction of rotation to be such that the lower portion of the right-hand sector is approaching towards the eye while its upper portion is receding, as indicated by the arrows, the relative positions after three successive eighths of a revolution will be as shown in perspective in Figs. 36, 37, and 38.

Considering first the relative motions of the left-hand sector A and the disc P, it is seen that in Fig. 35 this sector is in close contact throughout with the lower half of the disc; while between the sector and the upper half of the disc there is a cavity equal to a quarter sphere. In rotating from Fig. 35 to Fig. 36, a cavity is opening between the sector A and the lower half of the disc P, while the upper cavity is closing to the same extent. In Fig. 37 the opening and closing cavities are of equal size, each being one-eighth of a sphere. In Fig. 38 the opening cavity has become still larger, and the closing cavity still smaller; and after the next eighth of a revolution the opening cavity will be fully open, and the closing cavity entirely closed, the relative positions thus being again as in Fig. 35, except that each sector is now reversed end for end, having completed half a revolution upon its axis.

A similar opening and closing of cavities has been progressing simultaneously between the disc P and the right-hand sector B.

Throughout each revolution there are consequently two cavities simultaneously in process of opening, and two others in process of closing, all four alike changing at the same mean rate of increase and diminution. If therefore the disc with its pair of sectors be encased within a hollow sphere of the same diameter, and if steam be admitted into the two opening cavities and exhausted from the two that are closing, continuous rotary motion will be produced, driving the two shafts represented by the axes of the two sectors. When one of the two opening chambers is only just commencing to open, the other is half open; so that while the one is making no effort the other is in the position of best effort, and the mean effort of the engine is as uniform as that of a two-cylinder engine with cranks at right angles. It is also evident, as an interesting feature in the system, that, although the whole of the

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engine may be said to be contained within the sphere itself, yet the capacity of the engine is no other than the full capacity of the sphere itself, inasmuch as four quarters of the sphere are filled and emptied in one revolution.

Construction of Engine.—The names adopted for the three principal working parts are as follows. The intermediate librating disc P is called the piston, Plate 18; and the sectors B and A on the ends of the main and dummy shafts are called respectively the main and dummy blades. The piston, replacing the geometrical disc of infinitesimal thickness, has to be made of substantial thickness, and fitted effectively with a steam-tight packing all round its edge. The hinge union along the straight edge of each blade has to be made a cylinder of finite diameter instead of a geometrical line; and the junction has to be so contrived as to make a substantial hinge-joint that will stand the wear consequent on the rapid oscillation of the parts.

Thickness is obtained for the piston by deducting half its thickness from each of the two flat sides of each blade; that is, the disc P and sector B, originally depicted as in Figs. 39 and 40, are altered to the forms shown in Figs. 41 and 42. Two cylindrical ribs, having their axes in the middle plane of the piston, are formed on its opposite faces and along diameters at right angles to each other, Fig. 41; and into these are let circular lugs with eyes, formed on the straight edges of the two blades, Fig. 42, which are thereby hinged to the piston in the manner of an ordinary hinge, having a lug and socket with a pin through. The effect of these departures from the elementary geometrical form already described is to reduce the capacity of the engine by the amount of the cubic measurement of the hinges.

Hinge Joints.—Of the various forms of hinge joints that have been tried and used, the one which has been found the most suitable is constructed in the following manner, as shown in Figs. 10 to 13, Plate 15. Along the axis of each cylindrical rib R on the piston is bored a pin hole, the two holes being of equal diameter and

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intersecting each other in the centre of the piston. Through one hole is passed a pin C, Fig. 10, of the same diameter, on the two extremities of which are hinged the eyes of one of the blades. Into the other hole is inserted from opposite ends a pin D made in two portions, one of which is reduced in diameter and screwed for part of its length, so as to screw into a threaded socket in the opposite portion. The eyes in the lugs on the two blades, shown in finished form in Figs. 14 to 19, are bored out larger than the pins they are hinged on, and are fitted with thimble bushes, Figs. 20 and 21, which when worn can be taken out and replaced by fresh thimbles. This method of hingeing the blades to the piston has been found thoroughly satisfactory, enabling the pins and bushes to be readily replaced, and giving larger wearing surface than is obtained in other methods. The pins, Fig. 10, are made of hardened steel, lapped up, thus securing the utmost durability in conjunction with one of the simplest modes of manufacture. The thimble bushes in which the pins work, Figs. 20 and 21, are all of hard phosphor-bronze, which can be replaced by an ordinary workman at a mere nominal cost.

Steam Distribution.—The next point to be described is the admission of the steam to the cavities or chambers, and its release at the right periods of the revolution.

The back of each blade does duty as a revolving slide-valve; and as shown in Figs. 3 to 6, Plates 13 and 14, and Figs. 22 and 23, Plate 16, the spherical casing has a circular aperture cut in it, concentric with the shaft, into which is inserted a cylinder adjustable longitudinally, called the valve-block V, Figs. 26 to 28, Plate 16; the inner flat end of this block acts as a fixed valve-face, Fig. 26, having steam and exhaust ports made through it. The position of the ports is so arranged as to admit steam into each chamber while it is beginning to open, to cut off when deemed desirable, and to release when the chamber is beginning to close. While one chamber on either side of the piston is receiving steam, the opposite chamber on the same side of the piston is exhausting. Thus in each revolution of the engine four chambers are called into play, which

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have each their alternate periods of pressure and exhaust, just as in an ordinary reciprocating engine having a pair of double-acting cylinders coupled at right angles. In both sides of each blade is cut a notch N, Figs. 14 to 19, opening to the slant side of the blade from the valve-face at back; and the admission and release of the steam are effected in each revolution by these notches passing the ports in the face of the valve-block, Figs. 24 and 25. When the hinge of either blade is horizontal, Fig. 24, Plate 16—that is, at right angles to the plane of the main and the dummy shaft, which is supposed to be a vertical plane—the chamber between the piston and the lower side of that blade is absolutely closed, and the chamber above is full open. When by a quarter of a revolution the hinge has become vertical, Fig. 25—that is, has fallen into the plane of the main and dummy shafts—the chamber on the right-hand side of the blade is half way towards being closed, and that on the left-hand side is half way towards being full open. The steam port must therefore be situated on the opening side and the exhaust port on the closing side, as illustrated in the two diagrams, Figs. 24 and 25, which are supposed to be looking in the direction of the axis of the main shaft and towards the valve-face.

In Fig. 24, Plate 16, the hinge of one blade being horizontal, the upper chamber belonging to that blade is full open, and about to begin to close; and the lower chamber is shut, and about to commence opening. Rotation in the direction of the arrow will bring the lower notch N over the steam port, and admit steam into the opening chamber. The upper notch N will come over the exhaust port, and release the steam from the closing chamber.

Supposing it be required to cut off at half stroke, the steam will have to be admitted into the opening chamber and released from the closing chamber during the whole of the rotation from the position shown in Fig. 24 to the right-angled position shown in Fig. 25: that is, during a movement of the system through 90° or half of 180°. In this case the notches N in the blade are each made $\frac{90}{2}$ degrees wide, as is also the steam port; and the centre line of the steam port is at $\frac{90}{2}$ degrees with the vertical and horizontal positions of the hinge. In Fig. 25 the notch on the steam side is seen to have just passed the

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steam port, and to have cut off the steam; while the notch on the exhaust side is still over the exhaust port, and will continue to be so during the next quarter revolution, that is until the closing chamber is entirely closed.

Similarly any fraction of cut-off may be obtained, and the dimensions determined of the notches and steam port. Suppose it be wished to cut off at $\frac{n}{10}$ of the half-revolution or $\frac{n}{10}$ of 180°: the notches must be $\frac{n}{10}$ of 90° wide; the steam port will be the same width; the opening edge of the steam port will be at a distance of half the width of the notch from the vertical line below the centre of revolution, that is it will be $\frac{n}{10}$ of 45° from the vertical; and the centre line of the steam port will be $\frac{n}{10}$ of 90° from the vertical line below the centre of revolution. The notch will then admit steam at the moment the lower chamber commences to open, and will continue to do so while the blade revolves through an angle equal to twice the width of the notch, that is through twice $\frac{n}{10}$ of 90° or through $\frac{n}{10}$ of 180°, that is through $\frac{n}{10}$ of the half-revolution.

The cut-off is here spoken of in terms of the half-revolution, because, although the half-revolution of the blade in either chamber corresponds with a change from close shut to full open, and the quarter revolution with a change from close shut to half open, yet the chamber by no means opens and closes uniformly with the revolution of the shaft throughout the intervening phases. The comparison between the varying angular rate of opening and closing of the chamber and the uniform angular rate of revolution of the blade is given by the simple equation $\sin \theta = \tan \phi$, where θ is the angle of rotation of the main shaft and ϕ is the angle of opening or closing of the chamber. This relation is shown by the diagrams, Figs. 8 and 9, Plate 14, by means of which it can be determined at what fraction of the half-revolution the steam must be cut off in order to cut off at a given fraction of the stroke itself. The best point for cut-off depends of course upon the initial pressure available and the limit of weight of the engine.

Valve-Faces and Blocks.—The fixed valve-face has been made concave, and against it a plate on the blade has been pressed outwards

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by springs. Another plan has been to make both faces rigid, without any springs, the fixed face convex and the revolving face concave: so as, without spoiling the contact of the faces, to allow for the blades being slightly displaced laterally by the yielding of the parts through the infinitesimal bending of the shafts under the lateral pressure. But the fixed convex valve-face has now given way to the flat valve-face, Figs. 26 to 28, Plate 16, which allows more room for making a satisfactory hinge-joint; for it is seen from the diagram, Fig. 7, Plate 14, that the valve-face limits the room for the hinge work, inasmuch as, when any chamber is completely closed, the boss containing the hinge-pin of the other blade is brought close over against the valve-face. The original concave valve-face gave still more room for the hinge work; but it involved making one valve-face movable, and keeping it pressed up by springs.

The steam and exhaust passages are cored in the castings forming the two halves of the spherical casing, as shown in Figs. 3 to 6, Plates 13 and 14, and in Figs. 22 and 23, Plate 16. They are continuous from the main half into the dummy half when the two halves are bolted together; and are in communication respectively with the steam and exhaust ports in each of the two cylindrical valve-blocks. The two passages in the dummy half of the casing are blind, Fig. 6; while those in the main half communicate respectively with the boiler steam-pipe and with the exhaust-pipe of the engine, Figs. 3 to 5. The steam passage in the main half of the casing contains the throttle-valve at T, Fig. 3, whereby the supply of steam is regulated simultaneously to both the main and the dummy half of the engine. The arrows on the drawings show how, when the two halves of the sphere are bolted together, the passages effect a continuous communication from the main steam-pipe, past the throttle-valve, up to the main and dummy valve-blocks, and back again from these to the exhaust-pipe.

Packings.—For making the chambers steam-tight by packings round the circumference of the piston and on the convex surface of the blades, it has not been found advisable to make a continuous ring round the circumference of the piston, because that would

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limit the length of the hinge-pins. The piston packing is therefore made in four segments, as shown in Fig. 29, Plate 16; the ends of these fit tight against the four horse-shoe pieces, Fig. 30, which go round the lugs of the blades that form the hinge-joints; these four segments or quarter rings of packing, together with the four horse-shoes, form a continuous line round the piston, and are pressed outwards against the inner surface of the sphere by suitable springs placed underneath each segment. There are grooves G milled out in the backs of the blades, Figs. 17 and 19, Plate 15, into which are inserted short segments, Fig. 31, Plate 16; the ends of the segments hook under the horse-shoes, as shown in Fig. 31, so that they fit them tight, but yet can oscillate round them, as they have to do on account of the relative motions of the blades and piston. The straight joint between the cylindrical surface of the rib R on the piston, Figs. 11 and 12, Plate 15, and the meeting edge of the flat sides of the blade, is packed by a plain rectangular packing strip of phosphor-bronze, let into a straight rectangular groove J in the edge of the blade, Fig. 18; in the bottom of the groove are bored three holes to contain three small helical springs behind the packing strip. The flat surfaces, where the inner ends of the lugs on the blades are in contact with the outer ends of the rib R on the piston, are dependent for steam-tightness upon correctness of fit; they are not found to become leaky in working.

Piston, Blades, and Casing.—The piston, Figs. 11 to 13, Plate 15, is made of phosphor-bronze, which gives good wearing surfaces wherever the blades are in contact with it; and at the same time it can be cast to pretty nearly its required form. It is machined all over, to obtain perfect symmetry and balance. The blades, Figs. 14 to 19, are of steel, the lugs and shaft being all in one piece with the solid mass of the blade itself. They are shaped to their finished form by means of proper jigs and cutters. The casing, Figs. 3 to 6, Plates 13 and 14, is of cast iron, of good cylinder metal.

Lubrication.—A tank in the bedplate of the engine contains the lubricant, in which is immersed a small plunger-pump, as shown in

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Figs. 32 to 34, Plate 17. The plunger is raised by a slow and intermittent ratchet-motion M from the main shaft; and in its downward stroke is driven by the wheel W, which falls into gear with the worm on the shaft when the plunger has arrived at its highest position, causing it to descend promptly. By this means a definite small quantity of lubricant is injected at adjustable regular intervals with perfect certainty; and being supplied by the quick stroke of the plunger it is made to enter all the oil passages, instead of being absorbed by one only. Along the centre of each shaft is bored a longitudinal oil passage, with two radial branches through the body of each blade to the hinge thimbles; into the dummy shaft the oil enters through the back end of the shaft, which is accessible; and into the main shaft it enters through a cross hole opening into the central longitudinal passage. The centrifugal force carries it through the branches in the blades to the outermost extremity or bottom of the hinge thimbles; these therefore get a change of oil at every stroke of the plunger, while at the same time they are kept always full by centrifugal force.

Efficiency.—With regard to the efficiency of the spherical engine, which has hitherto been applied only to the direct driving of dynamo-electrical machines, a good many experimental tests have been made by the writer, as also previously by Mr. Tower. For these tests the water dynamometer of the late Mr. Froude, described by himself in a former paper (see Proceedings 1877, page 237), was employed, being particularly suited for the purpose, as it gives a steady resistance with entire freedom from local heating. A run of five minutes being ample for a test, the steam consumed during that time was exhausted into a tank, and the water condensed was compared with the work done. In this way were obtained in one experiment, with a 10-inch engine running at 600 revolutions per minute, two corroborative results of no more than 35 and 37 lbs. weight of steam consumed per brake-horsepower per hour.

Durability.—Ample experience of the durability of the engine has shown that the parts working under pressure do not seem likely

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to wear appreciably unless the oiling should be neglected. The first engine made by the writer's firm was run for a fortnight at an exhibition in August 1883, and was then put in place to light his works, where it commenced running in October 1883. Since that time, although there has been plenty of night work requiring the engine to be kept running even in summer, none of its parts have been replaced, and it is still running as quietly and well as on the first day it was started. It is 7 inches in diameter, and runs at 650 revolutions per minute. There have been two cases of fracture in two of the engines of earliest make, one at Portsmouth Dockyard and one on board the steamship *Dacca*; the fractures occurred from an oversight in workmanship causing weakness in certain parts now effectively strengthened; but there were no signs of wear and tear in the working parts. The engines used for the electric lighting of trains on the Great Eastern Railway have continued running since 26th October 1884 with perfectly satisfactory results. The engine is coupled direct to its dynamo specially made, the two being together on one bed-plate. The whole is mounted on the top of the locomotive boiler behind the dome, thereby avoiding any encroachment on the footplate space; and the steam can be taken direct from the dome. The regular speed is between 1000 and 1100 revolutions per minute.

Reversing.—The reversing of the engine is simply effected by turning the steam into the exhaust passages and exhausting through the steam passages.

Discussion.

Mr. HEENAN exhibited one of the spherical engines which had been running during the last six months on the Great Eastern Railway. It had lately been taken to his works in Manchester to be fitted with an improved governor. The inside of it had not been touched, and

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(Mr. Heenan.)
it was in just as good a condition as when it was started; and it was now going back to take its place again where it was before. The speed at which it had been running on the Great Eastern Railway during the last six months was 1000 revolutions per minute.

Mr. R. E. B. CROMPTON said he had used a great many of the spherical engines, and could give them a very good name. He had manufactured a great portion of the electric lighting machinery used on the Great Eastern Railway, and could state that the results had been extremely satisfactory. It was difficult for any one who saw the small casing mounted on the back of the locomotives on that railway to believe that it contained not only a dynamo machine but also a steam engine, and that the two drove sixty electric lights, each capable of lighting a carriage compartment thoroughly, and in some cases lighting two third-class compartments; the size of the casing seemed only sufficient to contain the dynamo itself. Having had the opportunity of seeing the inside working surfaces of the engines after running for a considerable period, he could corroborate the statement in the paper that these working surfaces appeared to remain in a perfectly smooth condition: in fact in such a condition as, judging from experience with ordinary engines, would lead to the expectation of a long life for the engines. In these high-speed engines, as had been stated in the paper, everything depended on thorough lubrication; and he wished to call attention to the ingenuity of the slow-speed oil-pump here applied, of which very little had been said in the paper. This mode of lubrication he thought would repay careful examination. His remarks upon the engine could only be in the nature of praise. It was a most difficult and puzzling piece of mechanism to understand until taken to pieces, so that the parts could be examined separately. It was better shown, he thought, by the elementary wooden model exhibited than could possibly be done by any number of diagrams.

Mr. JOHN ROBINSON mentioned that when this paper had been offered to the Institution he had been asked to look it over and to see whether it was a fit paper to bring before the meeting; and as

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one result of its examination he confessed he agreed with Mr. Crompton that the engine was a most puzzling one. When he had been asked whether it was likely to be an efficient engine, not having seen one at work, he found the question most perplexing to answer. To this engine might certainly be applied the old motto which had been employed for so many other things, *multum in parvo*. Reference had already been made by Mr. Crompton to the small size of the engine, and to its occupying so very small a space in consequence of its being altogether self-contained and without any reciprocation in the ordinary sense, so that it seemed a sort of mechanical puzzle. All mechanical engineers remembered from their apprenticeship the efforts that had been made for constructing rotary engines and spherical engines. The great difficulty in those former times had been the question of packing, so as to keep the surface of the piston, in whatever form it might be, sufficiently steam-tight against the surface of the casing. The conclusion at which he had himself arrived, in reading that part of the paper which spoke of the efficiency of the engine and the length of time that it had been at work in driving the dynamos on the Great Eastern Railway, was that an engine which seemed so eminently fitted to run at high-speeds with no change of motion—all revolving in the same direction without constant reciprocation or reversing of motion—running regularly, and well-fitted for driving dynamos for producing electric light—was at all events, if only as a piece of ingenuity, well worthy the attention of the members of this Institution, particularly at a time when the development of electric lighting was going on at such a rapid pace, and when there was so great a desire to have a very small and regularly running engine for producing these lights in workshops, or even in houses, where electric lighting he hoped was now being rapidly developed. On these accounts therefore he was sure that all the members would come to the conclusion that the spherical engine was well worthy the attention which had been recommended by Mr. Crompton; and not only the engine itself, but also the appliance for complete and continuous lubrication of the rubbing parts, which he believed was eminently necessary for the success of the engine.

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Mr. ROBERT WOODLEY said he had had his attention called to the spherical engine twelve months ago, when dealing with train lighting on the Great Eastern Railway. Wanting an engine which would occupy a very small space, he had looked at other high-speed engines suitable for coupling direct to dynamos; and he had at last come to the conclusion that there was nothing which would go into a smaller space than a spherical engine. He had consequently applied the engine which was now exhibited, fitting it with one of Mr. Crompton's dynamos, and putting it upon a locomotive. It was started about 26th October last, and since that time it had been running from 3.30 in the afternoon to 12.30 at night, and from 4.30 in the morning until daylight. When opened by himself about three weeks ago, the inside of the sphere was found to be much the same as when it was put together. As a matter of fact the tool marks were not out of the sphere, and the packing pieces were not yet perfectly smooth, very little wear taking place upon them as far as he could see. Since that first engine had been fitted, six other engines had now been fitted to locomotives, and they had been running without any breakdown whatever. Several alterations and improvements had been made in the governor, which was rather weak in mechanical detail; but with that exception the engines had given very great satisfaction to the railway authorities. Having had the particular handling of the engines, all he could say was that they had given him no trouble whatever. Perhaps it was not fair to say so much about the engine alone, when there was a dynamo which ought also to be considered. Of course the matter of leaving a train in the dark, even for a very few minutes, was of great importance. The matter of the brushes leaving the commutator, if only for a few seconds, or of the commutator not doing its work, was of very great importance; and during the whole of the time, five months or rather more, that these engines and dynamos had been running on the Great Eastern Railway they had never once let a light go out. Considering that there were no accumulators, and that the dynamos depended entirely upon the direct running of the engines, he thought the members would agree in regarding the result as satisfactory. In these remarks he had offered simply the

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result of what he had gathered from his every-day experience in the working of the spherical engine, as far as it had gone; and he hoped it would go on so continuously.

Professor GEORGE FORBES said he had followed the progress of the engine wherever he had had the opportunity during the last eighteen months with very great interest indeed. It was a most interesting engine, and although its action had been spoken of as puzzling to follow, it was not really complicated in any way. The engine was so totally different from any other that the tendency on first seeing it might be to pass it over altogether, as probably of no use at all. But on looking at it from a theoretical point of view there were so many respects in which it was far in advance of any rotary engine ever before produced, and it had so many of the advantages of the reciprocating engine without the disadvantages of the reciprocating motion, that from the first it commanded considerable attention. It could not be regarded as altogether getting rid of reciprocating motion, because it seemed to him that the disc did reciprocate, though to a limited extent; but the evils of reciprocation were reduced to a minimum by the small weight of the disc and the small extent through which it reciprocated. From a practical point of view there would be great difficulty in the packing to render the engine steam-tight in working; and a little fuller information would be acceptable as to the way in which that difficulty had been got over. When he first saw the engine in August 1883 it had seemed to him that a crucial point for determining its success or want of success was whether the packing could be satisfactorily accomplished. From the results of actual experience which had been given by previous speakers he was led to think all the serious practical difficulties had actually been overcome. One of the parts which he could not refrain from referring to was the appliance alluded to by Mr. Crompton for lubrication. That mode of lubrication seemed to be admirably suited to the high-speed engine, and might he thought be introduced with advantage into other high-speed machinery. It would be acceptable if the author would give a little more information

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(Professor George Forbes.)

respecting it, because to those who had not examined it carefully the rather meagre description in the paper did not bring out all its merits. From everything he had heard of the action of the engine, the practical difficulties seemed to have been perfectly overcome; and he thought it might be said to be without doubt the most efficient of rotary engines.

Mr. DANIEL ADAMSON was exceedingly pleased to hear that the force pump was employed to produce good lubrication in the spherical engine; and he believed there was a further great field open to forced lubrication, for such cases as the foot pivot of the heavily loaded upright shaft which he had mentioned at the previous meeting (Proceedings 1885, page 65). By this means it was rendered practicable to run heavy weights on cushions of oil, and not to have any metallic contact at all. Referring to the lubrication of this engine, he thought it would be interesting to know the velocity of the piston surface even when the engine was running at 600 revolutions per minute. Although the number of revolutions was enormously high, yet the space passed through was still small; and it would probably be found on ascertaining the exact piston velocity that there was not much risk of the engine coming to grief for want of proper lubrication.

Professor ALEXANDER B. W. KENNEDY considered the spherical engine was the very last and unquestionably the very best engine of a very old type—a type familiar to any one who had studied the vagaries of earlier attempts at rotary engines. The first form assumed by an engine based on the same idea as this, was, he supposed, the old "disc engine" of Davies, exhibited in 1851, which was taken to the *Times* office and drove the *Times* machinery until it had to be turned out. It had exactly the same number of moving parts as the Tower engine, and their kinematical relations to each other were absolutely similar; but the way in which they were fitted together, and the ingenuity with which the motion was carried out, were very different indeed. Not only the accounts which had just been given, but the results of his own personal knowledge as to the working of this spherical engine,

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had been without exception favourable. If any difficulty were experienced in understanding its motions, he might mention that they were described in great detail—not the motions of the engine as an engine, but the similar motions in a universal joint—in Reuleaux's book on the theory of machines, which he had translated six or seven years ago. The illustrations there given of the mechanisms on which the engine was founded would make clear to any engineer what the relative motions of the different parts were.* Strange as it might seem at first sight, these relative motions were exactly those of a drag-link coupling, in which drag-link and cranks were all made of the same length, but in which the four axes, instead of being parallel, that is meeting at infinity, were inclined together so as all to meet in one point, the distance of which from the cranks was made equal to their radius.

In this engine the practical difficulty to be dealt with, as had been rightly stated, had been the difficulty of packing; and he thought this difficulty had been got over partly by ingenuity and partly by the fact that the engine ran at so high a speed. He supposed it could not be imagined that the engine would remain steam-tight at a low speed; but if it did so, and if there was any evidence to that effect, it would be very important to know it. It would be of advantage if a detailed description were given of the lubricating pump, which was of great importance in the working of this engine, and would be so in the working of any engines for which it was used.

Mr. William Schönheyder remarked that it was of course necessary that the two half spheres forming the casing should meet together accurately, so that the inside surfaces of the two should be exactly even with each other; and this result he believed was here obtained by means of a couple of steady-pins. The steady-pins were very good in their way, but they offered a very small surface he thought for the very important duty of guiding the two surfaces so

* See Reuleaux's "Kinematics of Machinery," § 75, especially Figs. 260 to 263; and also §§ 88 to 91, where several rotary "disc" engines are analysed.

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(Mr. William Schönheyder.)

as to be accurately true with each other. That object he considered would be better effected by recessing one of the half spheres into the other in the manner of a very shallow spigot and faucit joint, which would offer larger and truer surfaces to come together—surfaces that could not be tampered with so easily nor injured so easily as the small steady-pins might be.

The packing which was said to do so well was no doubt perfect to a certain extent. At the same time the steam-tightness everywhere depended upon one ring only; there were not even two rings, such as it was usual to see in a steam piston. The speed was high, and there was hardly time for any leakage to take place. That lubrication was necessary to ensure perfect wear could be readily understood; otherwise it would be expected that the circular valve-face would wear itself out of truth, because the speed of the outer portion of the valve-face, owing to its greater distance from the centre, was twice or three times as great as the speed of its inner portion; and if any wear took place, leakage would no doubt ensue in time. The system of lubricating cylinders with oil continuously had been carried out for many years with the well-known sight-feed lubricators, which had the advantage of regulating the quantity supplied, and of enabling it to be seen whether the cylinders were being lubricated or not; he did not know whether either of these advantages could be realised with the lubricating pump of the spherical engine.

In regard to reversing the engine by simply turning the steam into the exhaust passages and exhausting through the steam passages, as described in the paper, it appeared to him that the effect would be to take steam for the full stroke and to exhaust for only one quarter of the stroke. This he considered required a little explanation.

Mr. ARTHUR PAGET did not gather from the description in the paper whether the lubricating pump was so arranged that any of the oil was led back to it from the engine, or whether it was supplied entirely with fresh oil. If the oil was led back to the pump, the consumption should not be great; but if the oil were all to be carried away in the exhaust, it looked as if the engine would require rather a large amount of oil for its lubrication.

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Mr. HENRY MAUDSLAY remembered being occupied forty years ago in drawing rotary engines for Joseph Maudslay, his uncle, who had devoted a very large amount of time and thought to scheming them. But at that time a rotary engine was a simple contrivance as compared with the present apparently complicated engine, in regard to which he had had considerable difficulty in arriving at a conclusion as to what its power was when at work. From the model exhibited and from the drawings it appeared that the two half spheres were really more than half filled with machinery, and it seemed as if there was but a very small amount of space for the steam to work in. He should therefore like to ask for a little more information as to the indicated power in comparison with any ordinary reciprocating engine or even rotary engine where the steam was always full on. For there seemed to be no time here for expansion, but the steam he thought must always be full on until the exhaust was opened. The difficulty therefore presented itself that the engine could hardly be considered economical of steam in working, except in so far as there was so small a space of cylinder to be filled with steam in each revolution. If there were a larger space vacant inside the sphere, then the steam might be employed expansively to perform more duty; but where the motion was so exceedingly rapid and the steam space so very small, he could not quite see how the engine was capable of developing power in comparison with an ordinary reciprocating or even rotary engine. In the spherical engine it appeared to him that the motion was of a compound nature, combining that of a reciprocating engine with that of a rotary engine. It was somewhat like the motion of the kneading machine that kneaded dough for making bread, in which there were two parts that intertwisted and rolled over each other but never touched, yet came so close together that they apparently confused themselves as if they were not geared together. The diaphragm interposed between the two blades in the spherical engine had a movement which might be compared with the sun's movement in the ecliptic, while it formed a sort of revolving piston in the inside of the sphere. The author of the paper was certainly to be congratulated upon the very clear and satisfactory description which it gave of the engine,

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(Mr. Henry Maudslay.)

considering how exceedingly difficult it was to follow mechanical motions of so peculiar a character, even with the aid of the very elaborate drawings by which the whole of the details were so well illustrated. The dummy shaft had indeed the appearance of doing no work, while taking half the steam of the engine; and it prompted the suggestion therefore whether in certain cases part of the power might not be taken off from the dummy shaft also, instead of the whole power of the engine being transmitted through the main shaft alone.

Mr. JOHN FIELDING asked what kind of packing was provided round the bosses of the hinge joints. The drawings showed packing provided round the circumference of the blades and piston, but he did not know what provision* was made for preventing leakage of steam at the hinges from one side of the blade to the other in the same half of the sphere.

Mr. BEAUCHAMP TOWER said the first spherical engine he made was 8 inches diameter in 1879. The next was a 12-inch engine which had been the subject of experiment at Messrs. Easton and Anderson's works at Erith during a couple of years. With regard to the proportion between the delivered and the indicated horse-power, he could only say he had taken a great number of indicator diagrams with that 12-inch engine, having made an indicator on purpose, specially adapted to the peculiar motion of the different parts of the engine; and he had found that the delivered horse-power was about 80 per cent. of the indicated, which was quite as good, he thought, as in the case of an ordinary steam engine of that size. With reference to steam consumption, the same 12-inch engine gave one delivered horse-power for about 60 lbs. of water per hour. That result was not so good as had since been obtained by Messrs. Heenan and Froude; but before they took the matter up he had under construction a 7-inch engine which was a great improvement over the previous engines; and he believed this engine

* This provision is described by the author by an addition made subsequently in page 103 of the paper and in Fig. 18, Plate 15.

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was the same which had been driving the electric light in their works for the last two years.

With regard to lubrication it might be interesting to the members to know that, in the friction experiments which he had had the honour of being engaged in carrying out for the Friction Committee of the Institution, the experimental journal had been driven by the above mentioned 12-inch spherical engine. In that case the engine had inevitably used a great deal of steam for the work done, because it was an engine which had actually given out 35 HP. at Messrs. Easton and Anderson's works, whereas the actual power required to drive the experimental shaft for the friction experiments was only about 3 HP.; so that, although the engine had been very convenient for the purpose, because it happened to be available when there was not any other to use, still it was quite unsuited for obtaining very economical results with regard to steam; and it would readily be understood that rather a heavy draught had consequently been made upon the generosity of Mr. Tomlinson, who had been so kindly supplying the steam for the friction experiments. When tried at Erith that engine had consumed about 60 lbs. of water per horse-power delivered. But the 10-inch engine which had since been made by Messrs. Heenan and Froude, and which had been driving the electric light in the workshops at Portsmouth during the past winter, was very much more steam-tight; and he believed it was giving the very fair result of somewhere between 30 and 40 lbs. of water per delivered horse-power.

With reference to the lubrication, the importance of applying a lubricating pump like the one shown had been specially pressed upon him by the result of the friction experiments; and it had certainly borne out the conclusion drawn from those experiments, that by giving sufficient lubrication metallic wear and tear was absolutely done away with, which had been found to be the case. He had seen several spherical engines that had been running for a year or two with this forced lubrication, and there really appeared to be no wear and tear at all: in fact, perfect lubrication was indispensable in an engine like this, which had to run at very high speeds. If it were lubricated sufficiently, metallic wear and tear was really done away with.

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(Mr. Beauchamp Tower.)

In regard to expansion, it would be seen that the steam port was a very short one compared with the exhaust; and with the length of port shown in the drawing the steam would be cut off at about half stroke, that is, the engine would be taking steam for about a quarter of a revolution.

The PRESIDENT enquired whether the cut-off was constant in any individual engine.

Mr. TOWER replied that it was so, the cut-off being determined by the size given to the steam port in the original construction of the engine. After the steam had been cut off, the next quarter revolution was performed by its expansion.

Respecting the difficulty of reversing by turning the steam into the exhaust, in that case the steam port, which was a short one, would become the exhaust port, and the exhaust would therefore be excessively cushioned. But that difficulty could be easily got over by putting a self-acting clack-valve in the valve-block face, to open outwards from the sphere into the original steam passage which in reversing had become the exhaust passage. That valve would be situated at the point to which the steam port would extend if it were prolonged and made as long as the exhaust port. In forward gear the steam outside the valve would hold it closed; and it would thus prevent the steam from entering at that part of the valve face. But when the steam passage was used for exhaust in reversing, the valve would open outwards of itself, and allow the full exhaust to continue throughout the entire stroke. It would be necessary of course to be contented with using full steam, without cutting off at all, when running reversed.

As regarded the question of steady-pins versus the spigot and faucit joint, for holding the two halves of the sphere true together, in the first two engines he had used a spigot and faucit joint, turning a shallow recess in the face of one hemisphere and a corresponding projection on the other. But he had found that to be a more difficult way of getting an exact and true position of the two halves of the sphere than by means of the steady-pins. The latter

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were very easily put in; the two halves were first bolted together for boring out, and there were true holes drilled through both flanges, and through these holes steady-pins slightly tapered at their ends could then be put in as nicely as possible; whereas the spigot and faucit joint was nothing more than one big steady-pin, which was more difficult to make without shake; and it was clear that it was of the utmost importance there should be no shake whatever. The two hemispheres were bored out by a special tool, which bored them out while they were both bolted together. The boring tool while carried round by its axis was at the same time traversed in a circle to which the axis of the boring tool was diametrical; and so it swept out a perfectly true sphere, while the two halves were fast bolted together. The steady-pins had certainly been found to be the best means of accurately putting together again the two halves of the sphere, after they had been taken asunder for inserting the working parts.

Mr. HEENAN, referring to the remark that the space in which the steam acted in the spherical engine was very small, pointed out that in each revolution of the engine the whole sphere full of steam was used, where expansion was not employed, with the exception only of the small space occupied by the bosses for hingeing the blades upon the piston.

In regard to lubrication, as Mr. Adamson had said, it was a great thing to have an engine running with so much oil as to avoid actual metallic contact. It would be seen that the main bearing had a brass or gunmetal bush; and it was packed at both ends with asbestos packing; both rings of packing were simultaneously tightened up by the single gland pressing on the outer ring, so that one set of tightening screws pressed both packings home. The bearing was swimming in oil all the time, and the oil could not get out except by leaking through the asbestos packing, which was made only a quarter of an inch thick in small engines; some oil therefore did leak through, and lubricated the internal part of the sphere. In large engines a sight-feed lubricator was used in addition to the force pump; and it had proved to be very useful.

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(Mr. Heenan.)

He had found "valvoline" lubricated better and cost less in the end than any other oil; it never clogged or carbonised, and being a pure hydro-carbon did not form a soap. Having done its work thoroughly in lubricating, it was discharged out of the exhaust pipe, and by a system of churning it against baffle plates it was arrested and collected in a well, from which it could be drawn off; and after straining, it was fit to be put into the oil tank and used over again. It was better not to allow it to run at once from the well into the oil tank, otherwise condensed steam might find its way also with it and cause mischief. Several samples of cheaper oils had been tried, but had proved inferior, some of them turning into a black mass almost like coal tar.

The cylindrical surfaces of the bosses of the hinge joints were rendered steam-tight by longitudinal straight packing strips let into grooves in the blades, as shown at J in Fig. 18, Plate 15, with springs behind them for pressing them outwards against the bosses. On the flat meeting ends of the bosses there was no provision for packing; but these surfaces were made as true a fit as possible in the first instance, and were free from pressure in working.

Mr. R. HURRELL FROUDE pointed out that the primary object of the forced lubrication was not to lubricate the surface of the sphere itself inside, but to get the oil supplied to the shafts and hinge-pins, the most important of all being the main shaft itself, which bore all the lateral pressure of the steam on the steam side of the blade inside the sphere. The overhung blade on the end of the main shaft stood out as from a cantilever, and the lateral pressure was wholly delivered upon the main-shaft bush; it was therefore of the utmost importance to keep this well lubricated. On one occasion when using bad oil he had seen an engine pull up dead two or three times, in consequence of the excessive friction on the main-shaft bearing.

The idea of taking off power from the engine through the dummy shaft would be feasible enough, provided power could be utilised conveniently from a shaft rotating at a speed that was not uniform. For while the speed of the main shaft was made to be nearly uniform,

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by help of a fly-wheel or by the machine driven acting as a fly-wheel, it would be seen that, consequent upon a well known fact in the working of a universal joint, the rate of rotation of the dummy shaft ranged between a maximum and a minimum in each half-revolution. This acceleration and retardation of the dummy shaft resulted no doubt in action and reaction between the hinge-pins and their thimble bushes, but not such as to cause any undue pressures.

The PRESIDENT said the members would no doubt remember that the first President of the Institution, George Stephenson, the father of railways, for the first and only paper that he ever contributed to the Institution had taken as the title "The Fallacies of the Rotary Engine." He had to-day been reading that paper. The writer devoted himself to showing that the use of a crank was not attended by any loss of power as compared with the application of steam direct to rotation. At that time and for some years later there seemed to have been quite a craze for a kind of engine in which the steam should be applied to produce rotary motion direct, so as to avoid the supposed disadvantage of reciprocating parts. But no successful rotary engine had to his knowledge ever been made until the present one was produced. This seemed to be successful, because it was perfectly balanced. It was not strictly correct to say that there were no reciprocating parts; but the one only reciprocating part was here in the direction of the axis of the shaft, besides being perfectly balanced. In an ordinary reciprocating engine there were revolving weights which could be balanced so as to make the shaft run perfectly true, if sufficient pains were taken; but there were also other parts reciprocating rectilineally towards and from the shaft, and these could not possibly be balanced. The consequence was that in running at quick speeds in an ordinary reciprocating engine there was very great difficulty in preventing vibration. That was what practically limited the speed to which ordinary engines could be run. In the present case what reciprocation there was took place longitudinally in the direction of the axis of the long shaft, which with its bearings, foundations, and so on, was a very favourable appliance for resisting the slight shocks due to the changes in the

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(The President.)

direction of the motion of the piston. Therefore in this case, in consequence of the small amount of the reciprocation and its favourable direction, the engine was able to run without shake at the enormously high speed of 1000 or 1100 revolutions per minute.

One very great advantage, which he thought had not been touched upon in the discussion, was that the engine developed a very large power in such a very small space simply from its high speed. It was a very compact engine indeed, with probably a larger power in proportion to the space occupied than any other engine.

There was another point also which he thought had not been sufficiently noticed, namely the very great pains that had been taken in the manufacture of the engine. It could not have been produced without a great number of special machines. It had been thoroughly thought out, and every part of it seemed to be almost riddled with tooling in all directions. In fact he thought the makers need not fear much competition, at all events on a small scale, because the manufacture was one which would have to be gone into with special tools carefully thought out for producing engines in such numbers as was now being done at Manchester. He thought the inventor and the makers deserved to be congratulated on having now achieved what engineers had been trying to do ever since the days of George Stephenson. It would have done the old man's heart good if he could have been present this evening to see at last a successful rotary engine.

He would now ask the members to accord a hearty vote of thanks to Mr. Heenan for his very able and interesting paper.

The vote of thanks was carried unanimously.

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ON THE HISTORY OF PADDLE-WHEEL STEAM NAVIGATION.

By Mr. HENRY SANDHAM, of London.

The origination of the propulsion of Vessels by Steam Power is claimed for several individuals and by several countries; but it is now generally admitted that to Great Britain is due the merit of having introduced and established the successful practice of steam propulsion.

The application of paddle-wheels to propel boats or vessels dates back to the time of the Roman empire, and even earlier; for it is known that the Chinese, Egyptians, and Greeks employed paddle-wheels for that purpose. In the Roman vessels the wheels were probably driven by slaves through some mechanical arrangement of spindles, wheels, pulleys, and ropes, or perhaps by mere direct action of manual labour; the feet also may have been employed. A drawing is given in Cutts' "Middle Ages" of an early fifteenth-century vessel propelled by oars which were worked by slaves lying on their backs in the vessel's hull, and pushing the oars with their legs and feet. The feet were kept in position by straps which enabled the oars, apparently balanced, to be lifted out of the water and carried back after each stroke. A rare and curious work in twelve books by Robert Valturius of Rimini, "De Re Militari," published in 1472 and printed by Beughem, contains representations of boats fitted with one pair and with five pairs of paddle-wheels.

1543.—It appears that Blasco de Garay, a Spaniard, made an experiment on propelling a vessel by mechanical power at Barcelona in 1543, before the Emperor Charles V., who paid all expenses incurred. Nothing is known beyond the record of this experiment, and the invention died with the inventor. No claim is said to have

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been raised upon it until 1826, after the true introduction of steam power for propelling vessels.

1682.—The earliest date recorded for the application, in Great Britain, of paddle-wheels to the propulsion of vessels seems to be 1682, in which year Prince Rupert's (1619–1682) state barge was propelled by paddle wheels. At the same period tug-vessels, with paddle-wheels driven by horses, were proposed to be used for towing sailing vessels against wind and tide.

1690.—Denis Papin, a French mechanician who was born at Blois in 1647 and died in 1714 or later, is next recorded as having propounded the propulsion of ships by mechanical means. In 1690 he proposed to propel boats by wheels "worked by racks and pinions working in steam cylinders;" and in 1707 he launched on the Fulda a boat with paddle-wheels, which was broken up by the boatmen at Münden. In 1681 he had already immortalised himself by the invention of the "digester" known by his name, which still continues in practical use at the present day.

1698.—Thomas Savery published his "Navigation Improv'd," in which he proposed to work paddle-wheels by a capstan between decks, turned by men.

1736.—A patent was taken out in 1736 by Jonathan Hulls, an English mechanician, for moving a boat by a steam engine, or rather "for the application of the atmospheric engine to actuate or propel a boat by paddles for towing vessels in and out of rivers and harbours." In 1737 he published in London a descriptive pamphlet with drawing, a copy of which is in the possession of Sir Frederick Bramwell. The proposal was to drive a fan or wheel at the stern of a boat, by a steam engine working a series of pulleys with straps or ropes passing over them; and there were arrangements for preventing a back motion of the stern-wheel.

1752.—Daniel Bernoulli (1700–1782) suggested in 1752 an arrangement of submerged artificial fins for propelling a vessel. In 1757 he was awarded a prize by the French Academy for his demonstration of the use and effect of paddle-wheels and other forms of propellers to be worked by steam power or the expanding gas of gunpowder. A propeller was exhibited at the Scientific Apparatus

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Exhibition at South Kensington in 1876, called the undulating propeller, the invention of A. H. Garrod, the idea of which appears to have been taken from the undulating fins of the pipe-fish and sea-horse. In 1882 a small boat was tried on the Thames with a fin propeller, the invention of C. F. Osborne. Mr. Pichler's propeller of 1860 was also of this fin class.

1753.—Through the activity of L. Euler, the mathematician, and Mathon de la Cour, an engineer of Lyons, France again took a prominent part in the mechanical propulsion of ships. Euler, like Savery, employed the vessel's crew in watches to drive an upright wooden shaft by long levers on each deck. On the top of the upright shaft was keyed a large crown wheel of wood having wooden teeth or pins which geared into a rung pinion on a horizontal shaft running across the vessel and through her sides, and carrying the paddle-wheels outside the hull. De la Cour drove his paddles by an endless rope-ladder suspended over two pulleys which were keyed on a horizontal shaft across the upper deck. The ladder was worked by men stepping on its rungs, exactly in the manner of the tread-wheel. The paddle-shafts and paddle-wheels were made to revolve by means of ropes from pulleys on the ends of the main shaft to pulleys on the paddle-shafts, which with their wheels were run out of the ship's side about her draught line. The shafts and wheels could be shipped or unshipped at will. In 1755 Canon Gautier of Nancy presented to the Royal Society of that place a paper on the proposals of MM. Euler and De la Cour, maintaining that the strength of the vessel's crew, working their machinery, would not be sufficient to give any great speed to a ship. As the only means of obtaining the requisite power, he proposed employing a steam engine; and pointed out several ways of doing so, and thereby of producing rotatory motion of the paddle-wheels. Practically however at that time the steam engine had not yet arrived at the stage in which it could be conveniently applied to the propulsion of vessels. Two conditions were wanting to adapt it to this purpose: namely rotatory instead of simple reciprocating motion, and continuous instead of intermittent motion of the engine itself.

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1782.—The Marquis de Jouffroy at Lyons in 1782 constructed a steam boat which ran for fifteen months on the river Saône. She was 140 feet long, 15 feet wide, and drew 3·2 feet of water. She had a horizontal single-cylinder engine, the cylinder being placed inside the boiler for warmth, as was subsequently done by Trevithick. Motion for the paddles was obtained by means of an iron frame sliding backwards and forwards with the engine stroke. To the top and bottom bars of the frame were attached double sets of pauls; and on the paddle-shaft, which ran through the frame, two cam-wheels were fixed. In the outstroke of the engine the cam-wheels were pushed by the pauls on the top of the frame, and in the instroke were pulled by those on the bottom, whereby an intermittent rotation was imparted to the paddle-wheels. In the South Kensington Museum is a sketch of this steamboat, lent by Mrs. Bennet Woodcroft, copied from a French print. The Comte d'Auxiron, a French nobleman of scientific pursuits, is also mentioned as having previously constructed a steamboat in 1774, and tried it on the Seine; and in 1775 M. Perier is said to have placed on the Seine a steamboat which had an engine of one horse-power.

1782.—James Watt, who was born in 1736 and died in 1819, perfected in 1782 his double-acting condensing steam-engine, continuous in its working, and controlled by the governor. This achievement opened out an entirely new and perhaps never-ending career for the steam engine. The fly-wheel on the main shaft secured the continuous action; while the crank, said to be an invention of Watt, though its application to the steam engine was patented by Pickard in 1780, supplied a simple and practical means of converting reciprocating into rotary motion.

1786.—This year forms another epoch in the propulsion of vessels by paddle-wheels. Patrick Miller of Dalswinton in Scotland had been experimenting for some time on the propulsion of boats by paddle-wheels worked by manual labour. In the Kensington Museum there is a coloured engraving, lent by Mrs. Bennet Woodcroft, of the "Edinburgh," a triple-hulled vessel designed by him and built in 1786 at Leith; she appears to have been 71 feet long, with 21½ feet extreme breadth, and 3 feet depth of hulls. Her paddle-

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wheels were 6 feet diameter, and 4½ feet in breadth; they had eight float-boards, 4¾ feet long, 9 inches deep. The wheels were turned by manual labour, as depicted in the engraving; they were set between two of the three hulls, one ahead of the other, and were housed in. The vessel was fitted with three masts, square rigged. As however she did not prove satisfactory, Miller was advised by his sons' tutor, James Taylor, to turn attention to the steam engine for the propulsion of his vessel. Accordingly in 1786–7 he entered into negociations with William Symington, an engineer and mechanic at the Wanlockhead Lead Mines, N.B., who in 1787 patented "his new invented steam engine on principles entirely new." Symington was to fit one of his new invented steam engines into a double-hulled boat of Miller's then on Dalswinton Lake. The boat was 25 feet long, 7 feet wide. Her steam engine under Symington's directions was made in brass by George Watt, founder, Low Calton, Edinburgh. In October 1788 the completed engine was placed in the boat, and connected to two paddle-wheels, driven with intermittent motion by rod and chain work attached to ratchet-wheels on the paddle-wheel shafts. The paddles were placed fore and aft in the boat's length. When the boat was started under steam a speed of 5 miles per hour was recorded. Symington's engine is now in the Kensington Museum, the property of Mrs. Bennet Woodcroft; it was re-instated in 1854 for the late Mr. Woodcroft by Mr. John Penn, and has been actually under steam. It is a single-acting double-cylinder engine; the two cylinders with open tops are only about 4 inches diameter and the stroke is about 9 inches. For a considerable period after the success of this steamboat on Dalswinton Lake nothing important seems to have transpired towards developing steam navigation.

1801.—William Symington however was employed in 1801 by Lord Dundas, governor of the Forth and Clyde Canal, to construct a steamboat to be used on the canal for towing the "sloops." In 1802 the "Charlotte Dundas" steamer was turned out, having a stern paddle-wheel driven by a double-acting horizontal engine with cylinder 22 inches diameter and 4 feet stroke. In March 1802 she towed on the canal two loaded sloops of 70 tons

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burden each, accomplishing 19½ miles in 6 hours against a head wind. Her career however was then stopped, through fear lest the canal banks should suffer destruction from the agitation of the water by the stern wheel. The speed when not towing reached six miles per hour. Her success induced the Duke of Bridgewater to give Symington an order for eight similar boats for service on his canal in England; but owing to the duke's sudden death the order was never carried out. Symington has the credit of placing the steering wheel of a steam vessel in the fore part, which was done by him in 1802.

1801.—Charles Earl Stanhope (1753–1816) in 1801 endeavoured to apply the duck's-foot propeller, proposed in 1752–3 by the Swiss inventor Génévois. It was revived in 1882, when a steam launch fitted with this class of propeller, proposed by Mr. Welton, was exhibited at the Naval and Submarine Engineering Exhibition at the Royal Agricultural Hall, Islington, London.

1807.—Robert Fulton (1765–1815), an American engineer, is said to have visited, inspected, and tried Symington's steamboat in 1802, and to have taken careful notes of her machinery. In 1803 experiments of his in France, with a steamboat on the Seine, are recorded as taking place. In August 1803 he is stated to have given an order to James Watt, Soho Works, Birmingham, for an engine of 20 H.P. for a vessel called the "Clermont," to be built in America. The diameter of the cylinder of this Soho engine was 24 inches, and the stroke 4 feet. The principal parts of the engine were forwarded to America in 1805. The vessel, her paddle-wheels and gear, and the subordinate parts of the engine, were designed and executed by Fulton himself. The steamer, completed in 1807, was 133 feet long, and 18 feet wide, or nearly 7½ times as long as she was broad, with 9 feet depth of hold. She ran from New York to Albany, 150 miles in 32 hours, and returned in 30 hours; after this trip she was advertised as a regular passenger and cargo trader between New York and Albany, and steamboats were thus established in America. Another steamer, the "Car of Neptune," had a length 7·44 times her breadth.

In America steam navigation was pushed on so energetically that

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in 1818 a steamer for ocean service, the "Savannah," was turned out, of 100 feet length and 26 feet breadth, or 3·84 times as long as broad, and drawing 14 feet of water loaded. She was the first steamer which crossed the Atlantic, though the voyage was not made entirely under steam. She was sent to St. Petersburg, and returned to New York. In connection with St. Petersburg it should here be mentioned that Mr. Charles Baird, an English engineer established there, fitted a Russian-built barge with steam machinery and paddle-wheels in 1815. A drawing of this vessel exists in the Museum at Kensington, which portrays the boiler as set in brickwork with a brick-built smoke-stack; whilst the paddle-wheels, having each two floats only, were fitted with gear for feathering the floats. The engine had a fly-wheel on the main shaft, and drove the paddles by geared wheels.

1811.—In this year the celebrated British steamer, the "Comet," was built at Glasgow by J. and C. Wood, for Henry Bell, an hotel-keeper at Glasgow. She was a wooden vessel 40 feet long on the keel, 10½ feet beam, and 25 tons burden. The machinery was made in 1812 by John Robertson of Glasgow, who died in 1868 at the age of eighty-six. The engine is preserved in the Patent-Office Museum. It is a table condensing vertical engine of 3 to 4 H.P. nominal, and is fitted with the bell-crank motion of James Watt for driving. The "Comet" had originally four paddle-wheels, two on each side of the hull, fore and aft of the centre of her length. Ultimately she was propelled by two wheels only, one on each side; the speed was 5 miles per hour. She plied between Glasgow and Helensburgh.

1813.—A larger steamer than the "Comet" was this year launched on the Clyde, named the "Elizabeth," built by Mr. Thomson. She was 58 feet long "aloft" (over all), and 11 feet broad amidships. She plied regularly twice a day between Glasgow and Greenock, at one-third of the fares charged by the stage coach.

In the same year a steamer commenced plying on the Yare between Yarmouth and Norwich on 9th August. A second vessel was subsequently added; but the enterprise came to a sudden end by

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the explosion of the boiler of one of the vessels on 4th April 1817, when several persons were killed.

1814.—Five steamers are recorded as running on the Clyde in 1814, whilst it would appear that ten steamboats had been turned out with success. Up to this time no steamer is mentioned as at work on the Thames. One at Bristol by Mr. Lawrence is spoken of, which plied thence to Bath, and was afterwards sent to the Thames by inland navigation. The opposition she met with however from the craft of the Thames watermen obliged her to return to Bristol.

1815.—A Clyde-built wooden steamer, the "Margery," was sent to the Thames in the summer of 1815, and began a regular service, once down and once up daily, between London and Gravesend. She was built in 1813 by J. and C. Wood of Glasgow, was of 70 tons burden, and had one engine of 14 H.P. nominal. This is the first regular passenger steamer on the Thames on record.

1815.—The "Margery" was followed by another wooden steamer built by J. and C. Wood at Glasgow, called the "Argyle," which came to the Thames from the Clyde round the Land's End. She was of 74 tons burden, 65 feet long on the keel, 14½ feet beam, with 3½ feet draught of water. Her paddle-wheels were on the first motion of the 16 H.P. engine. They were 9 feet diameter, 4 feet wide, with six floats in each wheel, 15 inches broad. The average speed was seven miles per hour. She was re-christened the "Thames," and plied between London and Margate.

1816.—The steamer "Caledonia," built by J. and C. Wood of Glasgow, was brought to the Thames. She was 94 feet long between perpendiculars, extreme breadth 15¼ feet, depth in hold 9 feet. She had a flat floor, and square bilge. She was fitted with two engines said to be by Boulton and Watt, one for each wheel: the first steamer recorded as fitted with two engines. They were together of 32 H.P. nominal, and had cylinders 23 inches diameter and a stroke of 2½ feet. The paddle-wheels were 13 feet diameter. James Watt afterwards bought the "Caledonia" for his own purposes, and fitted her out with new machinery and wheels. On 15th October 1817 he took her from Margate to the Scheldt and reached Rotterdam, whence on 23rd October he took her up the Rhine, arriving at

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Coblenz on 13th November. Owing to the shallowness of the river she was not able to proceed further up. She is said to be the first steamer ever run on the Rhine; and was finally sold to the King of Denmark.

A wooden twin-hull centre-wheel steamer, the "Prinzessin Charlotte," 130½ × 19⅓ feet, 236 tons burden, 14 nominal H.P., was built at Pichelsdorf near Spandau by John Rubie and J. B. Humphreys. She was launched on 14th September 1816, and began duty on 6th November following at Berlin, plying on the rivers Elbe, Havel, and Spree. She was the first steamer built in Germany; and was followed by other vessels built at Potsdam, having engines of 40 nominal H.P. by Boulton and Watt.

1817.—Elias Evans, a shipwright of Frinsbury near Rochester, coming thence to London in 1815, designed and built on the Thames some small schooners and sailing vessels, and soon turned his attention to the construction of steamers. In 1817 he launched the "Sons of Commerce" steamer, 85 feet by 25¼ feet by 8 feet, of 77 tons burden, mean draught of water 3½ feet; engines by Boulton and Watt of 20 H.P. nominal; diameter of cylinders 26¾ inches, stroke 2½ feet; diameter of paddle-wheels 10 feet. She was followed by the "Favorite," "London," and "Diana"; and by a vessel called the "Victory," which ran to Margate in 1818 with the "Favorite."

It appears from an advertisement in the *Times* of 8th May 1817 that a steamboat called the "Weser" commenced to ply upon the river of that name between Bremen and Braake. She was owned by Frederick Schroder, and was fitted with an engine of 14 H.P. by Boulton and Watt.

1818.—David Napier of Glasgow in 1818 built a sea-going steamer, the "Rob-Roy," of 90 tons burden, and 30 nominal H.P. She plied regularly between Greenock and Belfast, and afterwards ran between Dover and Calais.

In his work on the steam engine and steam packets, 1818, Mr. George Dodd records that two of his Thames steamers, the "London" and the "Richmond," carried on their station within four months 10,000 passengers. He describes his plan for lowering

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the chimney of these steamers, for enabling them to pass under the bridges; and records his proposal of water-tight iron bulkheads for dividing wooden vessels into compartments.

In 1819–20 two steamers appear to have been run by Mr. George Dodd between Holyhead and Dublin: the "Talbot," built 1819 by J. and C. Wood, Glasgow, 150 tons, 30 nominal H.P.; and the "Ivanhoe."

1821.—Evans built the earliest steam vessels recorded for the royal mail service. They were the "Lightning," 205 tons, 80 nominal H.P.; and the "Meteor," 189 tons, 60 nominal H.P. They both ran between Holyhead and Dublin. The "Meteor" was 126 feet long between perpendiculars, $22\frac{1}{3}$ feet extreme beam, $13\frac{2}{3}$ feet depth of hold.

In the same year, 1821, Evans turned out the "Union," 75 feet long, and $12\frac{1}{4}$ feet extreme breadth, with 7 feet depth of hold, and 53 tons burden, having a single engine only. She was speedily followed by larger and more powerful vessels for coast voyages: the "City of Edinburgh," built by Wigram and Green of Blackwall for the London and Leith trade; and the "James Watt," built by J. and C. Wood of Glasgow. The "City of Edinburgh" had a pair of engines by Boulton and Watt of 80 nominal H.P. Her wheels were on the second motion from the engine, 18 feet diameter, 8 feet wide, each with sixteen floats of 2 feet breadth. Blow-out pipes, brine pumps, and bilge injection are said to have been first applied in this vessel. The "James Watt" was $141\frac{3}{4} \times 25\frac{1}{2} \times 16\frac{1}{2}$ feet, tonnage 420. The form of her hull was deemed an advance, her greatest transverse section being amidships; and all her floors crossed the keel, so that she had no half-floors. She had two engines of 100 nominal H.P. together; her wheels were on the second motion and were 18 feet diameter and 9 feet wide, with sixteen floats of 2 feet breadth. At $10\frac{1}{2}$ feet draught of water the speed was determined as 10·03 miles per hour. She was the first steamer entered at Lloyd's, being registered there in 1822.

In 1821 the "Medusa" steamer, built by Evans, should be noted as the earliest that is mentioned as having oscillating engines: the original invention in 1785 it is said of William Murdock. A model made by Murdock of an oscillating engine was shown

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in 1858 at Aston Hall, Birmingham, and is still in existence. Goldsworthy Gurney (1793–1875) effected substantial improvement in oscillating engines in the early part of the present century; in 1813 they were the subject of a patent by R. Witty; and Joseph Maudslay, by his construction of them in 1827, under the title of improved vibrating engines, firmly established their reputation.

Steam vessels now appeared with great rapidity all round Great Britain; and also in Ireland—the City of Dublin Steam Packet Company being founded in 1824, whose first steam vessels were the "Mersey" and the "Liffey."

Long-Voyage Steamers.—In 1825 the first steamship voyage to India took place. The "Falcon" sailing vessel, 84 × 22 × 11½ feet, 176 tons burden, was fitted with paddles and steam machinery as auxiliaries to her sail-power. She arrived at Calcutta safely, and was bought by the East India Co.

The "Enterprise" steamer, 122 feet × 27 feet, 470 tons, and 120 nominal H.P., having an average speed of 8·79 miles per hour, left England in August 1825 for Calcutta. She reached her destination in 113 days all told; 103 days actually under steam, 10 days being consumed for renewals of fuel. Her commander, Captain Johnson, is said to have received a present of £10,000 for this successful voyage; the Indian government bought the steamer for £40,000.

In 1829-30 the "Hugh Lindsay" steamer, built at Bombay, 411 tons, 160 nominal H.P., carrying 5½ days' coal with 11½ feet draught of water, made a voyage from Bombay to Suez and back. This vessel's performances led to the establishment of the regular mail service between England and India, viâ Alexandria and Suez.

1830.—A service of paddle steamers was begun on 5th February 1830, between Falmouth, Malta, and Corfu, at that time with the Ionian Islands a British protectorate. The "Meteor" government steamer first conveyed the Mediterranean mails from Falmouth, which had previously been taken by sailing vessels. She was very quickly assisted by eight other steamers, the "Echo," "African," "Carron," "Columbia," "Confiance," "Firebrand," "Hermes," and "Messenger." The longest passage out and home occurred in 1831,

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namely 55 days by the "Meteor;" the shortest was also in the same year, 36 days by the "Messenger." The sailing packets had required an average of three months to perform the out voyage from Falmouth to Corfu only.

1837.—It appears that in this year government contracted with the Peninsular Steam Navigation Co. for a definite service of steamers to carry mails from Falmouth weekly to Vigo, Oporto, Lisbon, Cadiz, and Gibraltar. In 1834 the Admiralty were directed to arrange for a monthly extension to Alexandria of the existing Malta and Corfu service; the extension was carried out completely in February 1835. The "Hugh Lindsay" was to be sent at stated periods to and from Suez and Mocha with the mail, and to be assisted by the steamers "Atalanta," 616 tons, double engines of 210 nominal H.P.; and "Berenice," 664 tons, having two engines of 115 nominal H.P. each. Both these vessels carried one long gun; they were to run regularly to and from Mocha and Bombay. In 1840–43 the present Peninsular and Oriental Steam Navigation Co. had completed arrangements with the home and Indian authorities for the Indian mail service, with steamers of not less than 400 nominal H.P. In 1843 the service was extended to Calcutta; in 1845 to Ceylon and Madras; and in 1847 to China.

Royal Navy.—Here may be mentioned the following steam frigates with paddle-wheels and wooden hulls, built for the royal navy, and celebrated for long and valuable service.

1825.—The "African," 295 tons, 90 H.P., built by Sir R. Seppings. The "Avon," 361 tons, 170 H.P., built by Graham. The "Kite," 300 tons, 170 H.P.; and the "Lucifer," 387 tons, 180 H.P., built by Messrs. Humble and Hurry.

1827–30.—The "Rhadamanthus" and "Dee," about 800 tons, with side-lever engines of 220 nominal H.P. by Maudslay; speed 8¼ knots. The "Rhadamanthus" carried four broadside guns on upper deck, and was engaged in first Kafir war. Both these vessels were running in 1863 as store ships.

1834.—The "Blazer," 527 tons, 120 H.P., and the "Tartarus," 523 tons, 136 H.P.; both built by Sir William Symonds.

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The "Gorgon," built in 1837 by Sir Wm. Symonds; 1111 tons burden, 320 nominal H.P.; engines by Seaward on a new plan introduced in 1839 and ever since known as the "Gorgon" engine.

The "Cyclops," built in 1839 by Sir Wm. Symonds; 1195 tons burden, 1862 tons displacement, 320 nominal H.P.; engines by Seaward. These engines of Seaward established the Gorgon type of marine engine.

The "Penelope," originally designed for a 46-gun sailing frigate, in 1843 was cut in two at Chatham Dockyard, drawn asunder, and lengthened about 63 feet, to receive engines, boilers, and machinery: perhaps the earliest wood-built vessel thus treated. When lengthened she measured 245 feet in length, and 1780 tons burden. She carried guns on the broadside. Her engines were of the direct-acting or Gorgon type, 700 nominal H.P. Their total weight with boilers and paddle-wheels was 435 tons.

The "Retribution," built in 1844 by Sir Wm. Symonds; 1641 tons burden, 800 nominal H.P.; engines by Maudslay and Field, on the double-cylinder system with T cross-head introduced by Joseph Maudslay in 1841. Two years later these engines were removed, and a pair of oscillating engines by Penn were substituted of 400 nominal H.P.; the speed was then 10½ knots, a little more than the original speed. She carried twenty-six guns on the broadside, and two pivots, the latter being 68-pounders of 95 cwts. each; she was the heaviest armed paddle-steamer the navy then possessed.

The "Terrible," twenty-one guns, built in 1845 by Oliver Lang; 1850 tons burden, 800 nominal H.P. Her engines by Maudslay and Field were similar to those of the "Retribution."

The "Tiger," built in 1849 at Chatham by Mr. J. Edye; 1221 tons burden, 400 nominal H.P. Her engines it is believed were by Seaward. During the Russian war in 1854 she grounded at Odessa in a fog, was surrendered to the enemy, and was sunk by them.

The "Janus," built in 1844 at Woolwich or Deptford, by Lord Dundonald; 763 tons burden, 200 nominal H.P. The ship, her boilers, engines, and machinery, were all designed by Lord Dundonald himself. She was fitted originally with rotary engines

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designed by him, which were geared to the paddle-shaft; they proved a complete failure, and were removed. She was afterwards fitted with direct-acting or Gorgon engines, but was not considered a success. The "Janus" had bow and stern alike sharp, and was capable of going either end first at equal speeds, to avoid turning. Her hull sections were similar semi-ellipses. She was the earliest vessel arranged to go either end first; and had rudders capable of forming part of the ship's structure when not wanted for steering. This system, fore and aft ends alike, was afterwards greatly developed for paddle-wheel gun-boats.

It is worth noting that the first steamer in the royal naval service was the "Monkey" paddle-wheel tug, built at Rotherhithe in 1821 by Evans; 212 tons burden, 80 nominal H.P.

The next was the "Comet," built at Deptford in 1822 by Oliver Lang; 238 tons burden, 80 nominal H.P.

The third was the "Sprightly," built at Blackwall in 1823 by Wigram and Green; 234 tons burden, 100 nominal H.P.

The fourth was the "Meteor," built at Woolwich in 1824 by Oliver Lang; 296 tons burden, 100 nominal H.P.

In 1845 the "Odin" and the "Sidon," designed by Sir Charles Napier, were the first paddle-frigates carrying guns on the main deck. The "Odin" had direct-acting engines of 590 nominal H.P. by Fairbairn and Co. The "Sidon," 500 nominal H.P., was fitted with tank coal-bunkers; as the coal in them was used up, the tanks were filled with water from the sea; thus the vessel could be maintained at a mean draught of water.

About 1838 Captain George Smith appears to have covered the paddle-boxes of H.M. steamer "Carron" with a life-boat 25 × 9 feet, capable of carrying forty to fifty persons. Paddle-boxes covered by life-boats or other ships' boats were proposed about 1840 by three officers of H.M. dockyards, Messrs. Burr, Peake, and O. Lang. Of the three it would appear that Mr. Peake has chief credit both for originating and for maturing the idea. The securing and the launching of the boats on the tops of the paddle-boxes gave rise to much scheming. The "Penelope," "Retribution," "Terrible," and "Tiger," with many other paddle-frigates, were fitted with paddle-box

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boats. The paddle-box boats of the "Retribution" could carry a hundred men each. When manned for pulling with thirty-two oars they were half as fast again as any other boat in the ship.

In 1848 Mr. R. Taplin, of Woolwich Dockyard, brought out the telescopic funnel or smoke-stack adopted for the royal navy. He had previously about 1827 designed a steam-superheating apparatus for boilers.

Ocean Steamers.—Of British Atlantic-Ocean paddle-wheel steamships the earliest recorded were:—

The "Curaçoa," built about 1827 in England, and purchased by the Dutch Government; 400 tons burden, fitted with two engines of 50 nominal H.P. each. She went a voyage from Helveotsluys to Surinam in 27 days 11 hours, consuming 7·14 lbs. of coal per H.P. per hour.

The "Royal William," built in 1832, of 1200 tons and 180 nominal H.P. She came from Picton, Nova Scotia, to Portsmouth in 20 days. She was built at Quebec to run for a steampacket company between Halifax and Quebec. Her engines were made at St. Mary's Foundry, Montreal. She was eventually sold to the Portuguese government.

The "Great Western," promoted by Captain Claxton, R.N., and built in 1835 at Bristol by Patterson. Engined by Maudslay and Field. Her wheels were constructed on the cycloidal system devised by Joshua Field in 1837–8. Length between perpendiculars 212 feet, over all 236 feet; extreme breadth 35½ feet; depth of hold 23¼ feet; load draught 16 feet; 1340 tons burden; side-lever engines of 400 nominal H.P. The "Great Western" was fitted out at London, and sailed thence for Bristol and New York, 31st March 1838; she left Bristol 7th April, and reached New York 22nd April; speed attained 12·88 miles per hour. This celebrated vessel was broken up in 1858.

The "Sirius," 178 × 25⅔ × 18¼ feet, 450 tons register, 270 nominal H.P., built in 1838 by the St. George Steampacket Co., was afterwards chartered by the British and American Steam Navigation Co. to run to New York till their own vessel the

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"British Queen" was ready. She left Cork on her first Atlantic voyage on 4th April 1838, sailed four days, and arrived at New York on 22nd April, four hours before the "Great Western."

The "Royal William," which sailed in July or August 1838, was the first steamer from Liverpool to New York. She made two trips, if not three—18 days out, 15 home. Built by Wilson, tonnage about 700, with engines by Fawcett and Co. of 250 nominal H.P. This steamer was sent to open the line, whilst the "United States" was building. She was afterwards sold to the Peninsular and Oriental Co., and renamed the "Oriental." The two next steamers from Liverpool were the "President" and the "Liverpool."

The performances of the "Great Western" and "Sirius" led Mr. Cunard to come over to England from America in 1839, and start the celebrated Cunard line from Liverpool. The "Britannia," "Acadia," and "Caledonia" steamships were built for this line by J. and C. Wood of Glasgow and Greenock. Their dimensions were: 206 feet long between perpendiculars, 34½ feet extreme breadth; 22½ feet depth of hold; 1139 to 1155 tons burden. Their engines were constructed by Robert Napier of Glasgow on his side-lever system, and ranged from 440 to 450 nominal H.P. The cylinders were 72 inches diameter, stroke 6 feet 10 inches. Their wheels were 28 feet diameter. The tonnage was respectively 2·57, 2·58, and 2·53 times the nominal horse-power in the three ships.

The following tabulated statement of particulars of early and contemporaneous ocean-going paddle-steamers may be interesting:—

Vessels' Names.	Tonnage.	Horse-Power.	Tons per H.P.	Remarks.
Acadia . . .	1200	440	2¾	Very swift ship.
Oriental . .	1670	440	4	Speed 10½ knots per hour, when deep.
Great Western .	1340	450	3	Speed 12¾ knots per hour.
Great Liverpool	1543	464	3⅓	
British Queen .	2016	500	4	Fast ship when light.
President . .	2366	540	4½	Slow vessel always.
Liverpool . .	1150	404	2½	Slow ship, and crank.

The "Acadia" was built and engined at Glasgow in 1839–40, as before stated. The "British Queen" was built at London in 1838 by

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Curling and Young; 275 × 39½ × 27½ feet, lever engines by R. Napier of 420 nominal H.P., cylinders 77¾ inches diameter, stroke 7 feet; Hall's surface condenser was used. The "Liverpool" was afterwards widened by 7 feet, making her 393 tons larger; the proportion of power to tonnage by the alteration was decreased, but the ship's speed and weatherly qualities were found to be increased.

The establishment of the Cunard line in 1839 was followed by the rapid formation of other large steam navigation companies:—

1840.—Royal Mail, West India Co.
1837-1841.—Peninsular and Oriental Co.
1843.—Pacific Mail Co. (West India and Pacific Co.)
1850.—Collins line of American vessels.
1850.—Inman line.
1851.—African Mail Co.
1854.—Allan line; sailing ships 1823.

These celebrated companies, especially the Royal Mail and the Peninsular and Oriental, owned for the most part steamers of great size and power, of which it is impossible here to mention all. The Royal Mail Co.'s steamers were named after British rivers, the "Tay," "Teviot," "Shannon," "Thames," and so on. Their sailing port was Southampton. They have generally been considered as the typical fleet of paddle-wheel ocean steamers of their time. They were built in 1841–47; ranged from 1300 to 1880 tons; and were engined by Maudslay and Field, Ravenhill, Acraman, Caird and Co., Bury and Co., Scott and Sinclair, with an average of 450 nominal H.P. In 1860 the Royal Mail Co. possessed a fleet of 25 vessels of 47,000 aggregate tonnage, and 12,230 H.P. The Peninsular and Oriental fleet in 1860 comprised a total of 55 vessels of 75,000 aggregate tonnage, and 18,151 H.P. At that date the "Massilia," 1919 tons, 310×36 feet, and 400 nominal H.P., was built by Samuda Brothers.

The possibility of providing too much engine power in steamships was clearly demonstrated by the paddle-wheel vessels "Valetta" and "Delta" of the Peninsular and Oriental fleet. The "Delta," iron-built 1859 by the Thames Iron Works Co., 1953 tons,

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350 × 35½ × 24½ feet, was furnished with Penn and Sons' oscillating engines of 400 nominal H.P. taken without any alteration from her senior the "Valetta" of 983 tons; steam was provided by Lamb and Summers' boilers. The "Valetta" with 100 tons of coal on board had a speed of 14 knots per hour; the "Delta" with 400 tons of coal on board realised 14¾ knots per hour, although her capacities were more than double those of the "Valetta." The "Valetta" was re-furnished with smaller engines of about 250 nominal H.P.; after which she steamed as well as ever. The "Ruby" Gravesend packet in the first instance was also over-engined; smaller engines were afterwards substituted, with the result of an increase in speed.

Iron Steamers.—The celebrated large steamers hitherto dealt with were built of wood. The increasing price and consumption of wood for shipbuilding now compelled attention to iron. The late Sir William Fairbairn was the staunch advocate of the application of iron to shipbuilding.

The earliest mention found of an iron steamer is of the "Aaron Manby," built in 1820 at the Horseley Iron Works, Tipton, and named after her designer and constructor. The hull was sent in pieces to the Thames, put together in the Surrey Dock, and she went a voyage to Paris, landing there a cargo of rape seed at the Pont Royal over the Seine. Sir Charles Napier navigated the vessel, her machinery being in charge of the late Mr. Charles Manby. She had feathering-float paddle-wheels, designed by Mr. John Oldham. She was followed by several sister iron steamers, constructed by Mr. Aaron Manby at the Horseley Works, and at his works at Charenton near Paris. In 1845 the "Aaron Manby" was still running on the Seine.

In 1837 was built at Birkenhead by Mr. John Laird an iron steamer 198 feet long, 26 feet broad, 12¾ feet deep, 5½ feet draught of water, 582 tons, 180 nominal H.P., called the "Rainbow." She served the General Steam Navigation Co. between London and Antwerp or Rotterdam for many years, and was remarkable for being driven by a pair of upright or "steeple" engines by Messrs. G. Forrester and Co., Liverpool, which towered above her deck.

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Diameter of cylinders 50 inches, stroke 4½ feet; diameter of paddle-wheels 21½ feet; float-boards 10 feet long.

The attention of Lloyd's was first directed to iron as a material for ships about 1837, in which year the first iron vessel that received a class was built. This was the steamer "Sirius," of 180 tons, built in London under the inspection of Lloyd's officers, and owned at Marseilles. She appears in the supplement to the 1837 volume of Lloyd's register, having the A character without a term of years, and the notation "built of iron."

Progress on the Thames.—On the Thames much activity in steamers is recorded between 1830 and 1840. The "Sophia Jane" steamer, of 50 nominal H.P., built in 1828 by Barnes and Miller of Ratcliffe, was placed by them for service on the river. She was followed in 1829 by the "Kent," "Pearl," and "Essex," owned by the Milton and Gravesend Steam Packet Co., which had been founded in 1827. The General Steam Navigation Co., founded in 1825, possessed in 1860 a fleet of 44 paddle steamers, registering 21,500 tons, and 7000 nominal H.P., built of wood and of iron, and trading from London to Holland, Belgium, France, and along the east coast of England and Scotland. The "Trident," wood-built in 1841 by Wigram and Green, with lever engines of 260 nominal H.P., 197½ × 31 feet, 971 tons gross, served Her Majesty and the Prince Consort in 1842 as their yacht during a visit to Scotland. The "Waterwitch," "Vivid," "John Bull," "Clarence," "Soho," and "Sir William Jolliffe" were wooden vessels, built 1824–1840. The "Albion," "Seine," "Rhine," "Moselle," were iron vessels, built 1843–1852. Their passages were from London to Hamburg, Antwerp, Rotterdam, Ostend, Edinburgh, Hull, Yarmouth, and other ports.

The following particulars relate to the state of steam-vessel propulsion on the Thames.

1830.—St. Katherine's Dock Wharf was opened. The "Harlequin" steamer started on the first recorded excursion trip, to the Nore and back to London, on 9th April 1830. She carried 400 passengers.

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1834.—The Town Pier at Gravesend was formally opened. The "Star" steamer landed there 500 passengers from London. The "Comet" steamer also worked on this station at same date. The success of these two vessels secured the stability of the Star Steam Packet Co., which was founded in 1833, and by the end of 1834 had five steamers running up and down the Thames between London and Gravesend: "Star," "Comet," "Vesper," "Satellite," and "Planet." The "Vesper," wood-built 1836 by Fletcher; engines of 90 nominal H.P. by Miller. The "Meteor," iron-built 1844 by Miller, 170 × 18 × 9 feet, mean draught 4 feet, 274 tons burden, speed 12·68 knots per hour, 80 nominal H.P., cylinders 37 inches diameter, stroke 3 feet, paddle-wheels 15¾ feet diameter. These early vessels were replaced by the "New Star," built and engined in 1847 by Miller and Ravenhill, 180 × 17 × 9 feet, 271 tons burden, oscillating engines of 70 nominal H.P., feathering wheels; the "Jupiter," built and engined in 1849 by Miller and Ravenhill, 165 × 18 × 9 feet, 265 tons burden, oscillating engines of 80 nominal H.P., feathering wheels; the "Mars," built in 1852 by Wigram, 180 × 18 × 10 feet, 291 tons burden, oscillating engines of 90 nominal H.P., by Miller and Ravenhill, feathering wheels; the "Venus," built in 1854 by Mare and Co., 180 × 18 × 9½ feet, 291 tons burden, oscillating engines of 90 nominal H.P., by Miller and Ravenhill, feathering wheels.

1835.—The Terrace pier at Gravesend was built and opened, Mr. J. B. Redman being the engineer. This was the first work having hollow iron cylinders for the piers themselves, which when sunk into the river bed and secured were filled in with brick-work or concrete. The Star Company ran their steamers to this pier.

1835–7.—Woolwich Packet Co.'s vessels:—"Naiad," "Fairy," "Nymph," "Ariel," and "Sylph." The last-named was built in 1838 by Maudslay and Field, and engined by them, 30 nominal H.P. Later came the "Witch," a very swift wooden boat, built about 1844, with oscillating engines by J. Penn and Sons; the "Dryad," engined by J. Penn and Sons, speed 12·6 knots per hour, dimensions 123 × 14 × 6½ feet, gross tons 88, nominal H.P. 40; the "Metis," "Doris," "Elfin," and others. Mr. Thompson

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of Rotherhithe was the principal constructor of these Woolwich packets.

1838.—The Diamond Steam-Packet Co. started five vessels on the Long Ferry from London to Gravesend. Their names were: "Diamond," "Gem," "Pearl," "Topaz," and "Ruby;" later appeared the "Sapphire" and the "Emerald," originally the "Prince Albert." The "Ruby" was built by Wallis, and engined by Seaward in 1836; 155 × 19 × 10 feet, 272 tons burden, 100 nominal H.P., cylinders 40 inches diameter, stroke 3½ feet, paddle-wheels 17½ feet diameter, speed 13·17 knots per hour. In 1856 the fleet of the Star and Diamond Companies was entirely superseded by the railways on the north and south side of the river reaching to Tilbury and Gravesend respectively.

1840.—The London and Blackwall rope-railway was completed, Stephenson and Bidder being the engineers. The line was a double one, 3½ miles long, running on a viaduct of brick-arches all the way, and with a falling gradient towards Blackwall. The haulage at the rate of 25 miles per hour was effected by powerful stationary engines at each end driving huge drum-wheels. The engines at the London terminus in Fenchurch Street were about 400 nominal H.P. by Maudslay and Field; those at the Blackwall terminus were about 280 nominal H.P. by Barnes. In 1842 the railway company ran three steamers of their own from Blackwall to Gravesend in connection with their trains. These steamers were the "Railway," "Brunswick," and "Blackwall." The "Railway," built by Ditchburn and Mare in 1842, was 145 × 19 × 10 feet, 258 tons burden, with oscillating engines by Penn of 90 nominal H.P., giving a speed of 12·02 knots per hour. The "Brunswick," also built by Ditchburn and Mare in 1842, had direct-acting engines by Seaward of 90 nominal H.P., with 39½ inch cylinders and 3 feet stroke; the paddle-wheels were 15½ feet diameter. The "Blackwall" had a steeple engine of 90 H.P. by Miller and Ravenhill. The "Queen" by J. and G. Rennie, 160 feet long, with 9 feet depth of hold, speed 17 to 18 miles per hour, was also running at the same time on this station.

1841.—Waterman's Steam-Packet Co. Iron-built vessels, chiefly by Ditchburn, plying against the Woolwich Steam-Packet Co. and

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named "Waterman" Nos. 1 to 10. No. 10 was a swift boat. She had feathering-float paddle-wheels, the float-boards being narrow and deep, instead of wide and shallow.

The Woolwich Packet Co. and the Waterman's Packet Co. amalgamated in 1865, and worked the general passenger traffic of the Thames below London Bridge. These companies were absorbed into the London General Steamboat Co., founded 1875; which secured for itself a monopoly of the river passenger traffic both above and below London Bridge, in fact from Kew and Richmond up the river down to Southend, Sheerness, and the Nore.

1843.—In this year was turned out on the Thames at Blackwall by Miller and Ravenhill the "Prince of Wales" iron steamer, designed by E. Pasco. She was 180 feet long between perpendiculars, 22 feet beam, 10 feet depth of hold, 429 tons old measurement; side-lever engines by Miller, with 46-inch cylinders and 3½ feet stroke; nominal H.P. 136, speed 12·75 knots per hour. The steamer "Helen McGregor," built by Laird Brothers in 1843, should also be noted here on account of her engines of 248 nominal H.P. by G. Forrester and Co., of Liverpool, the earliest of which the writer is aware having inverted cylinders. The two cylinders were each 42 inches diameter with 4½ feet stroke; the connecting-rod worked between them, from a single cross-head common to the two piston-rods. The vessel had ordinary paddle-wheels 23½ feet diameter, driven at 23½ revolutions per minute. The steam pressure in the cylinders averaged 3¾ lbs. per square inch. Inverted-cylinder engines were the original idea of William Bull, who introduced them in 1790; they are still known as "Bull" engines.

Many instructive examples of marine engines on the direct-acting or Gorgon system were also at work in paddle-steamers between 1843 and 1853, some of which may be mentioned. The engines of the "Centaur," 565 nominal H.P., by Boulton and Watt. A pair of engines of 422 nominal H.P., by Scott and Sinclair. Double cross-head engines of the "Nimrod," 322 nominal H.P., by Bury. Double cross-head engines of the "Queen," 175 nominal H.P., by Fawcett and Co. Oscillating engines of H.M.S. "Black Eagle," 272 nominal H.P., by J. Penn and Sons. Engines of the "Thunderbolt,"

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326 nominal H.P., by Robert Napier and Sons. Single steeple-engine of the "Fawn," 67 nominal H.P., by David Napier. Steeple engines of the "Royal Tar," 161 nominal H.P., by Tod and MacGregor. Engines of the "Sampson," 593 nominal H.P., by J. and G. Rennie, said to be the first marine engines fitted with the locomotive link-motion.

1844.—The following are the names of some well-known short-voyage vessels on the Thames in 1844, both of wood and of iron :—"Father Thames," "Sons of the Thames," "Royal Adelaide," "Royal George," "City of Canterbury," "Sir Edward Banks," "William Wilberforce," "Red Rover," etc. For sea voyages to and from London in the general coasting service of Great Britain were employed, with many other steam vessels, the "Dundee" and "Perth," built by J. Wood in 1834, engines by R. Napier, 265 nominal H.P., wheels 24 feet diameter; "London," built by J. Wood in 1836, engines by R. Napier, 305 nominal H.P.; "City of Aberdeen," "City of Glasgow," and "City of London," built and engined by R. Napier in 1844, 405 nominal H.P., cylinders 70¾ inches diameter, stroke 6½ feet, wheels 28 feet diameter; "Duke of Sutherland" and "Earl of Aberdeen," built and engined by R. Napier in 1847, nominal H.P. 375 and 395 respectively, wheels 25 feet and 25 feet 10 inches diameter. In this connection should be mentioned a paddle steamer faithful both to her station and to paddle-wheels, the "Baron Osy," trading from London to Antwerp. The first steamer of this name, 400 tons, was built about 1840. A new "Baron Osy," 792 tons, 260 nominal H.P., built of iron by the late John Scott Russell, was placed on this station in 1855. In 1863 she was sunk in the Thames by collision, was raised, and was improved both in hull and in steam power. She then continued her work until 1875, in which year the present "Baron Osy" paddle-steamer was built by Mitchell and Co., Low Walker, Newcastle; 245 × 30 × 15½ feet, 1100 tons, and 300 nominal H.P. Her boilers, machinery, and engines on the oscillating compound system were furnished by Thompson and Co.

David Napier of Millwall turned out two remarkable iron-built vessels, with high-pressure upright or steeple engines driving

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feathering-float wheels of his own design; particulars of these vessels are difficult to procure. In 1839 he had improved the construction of iron ships by introducing double bottoms; and in 1842 and 1847 he introduced in the upright or steeple engines the use of two or four piston-rods with appropriate connections to drive the main shaft of the engine. The names of his steamers were the "Eclipse" and the "Isle of Thanet." The "Eclair" and "Rocket" were other celebrated iron-built steamers at this time.

1844.—Hitherto iron had not been adopted for the construction of ships for the royal navy. In 1844 two iron-built gunboats of 340 tons burden, 150 nominal H.P., are mentioned as completed at Glasgow; and in 1845 two other gunboats with iron hulls were turned out at Blackwall for the navy. In 1845 the iron yacht "Fairy," propelled by a screw, was built at Blackwall by Ditchburn and Mare for the Queen's use; 312 tons and 128 nominal H.P. The "Myrmidon" of 370 tons and 150 H.P., and the "Bloodhound" of 378 tons and 150 H.P., by R. Napier and Sons, Glasgow, with the "Birkenhead" frigate of 1400 tons, by John Laird, were also completed.

In the period 1845–1865 the four following companies were working small iron paddle-wheel steamers on the Thames between London Bridge and Westminster Bridge. Some of these vessels attained considerable speed, and are still at work on the same station under the London Steamboat Co.

1.—The Citizen Company. 1846.
2.—The Iron Steamboat Company. 1838.
3.—The London and Westminster Steamboat Company. 1835-6.
4.—The Halfpenny Fare Steamers (Dyer's Hall Company). 1846.

The first of these small companies ran boats fitted by Messrs. John Penn and Sons with oscillating engines of about 25 nominal H.P. Their boats were named Citizen A, B, C, etc., and were also called after the several city guilds: "Haberdashers," "Fishmongers," "Loriners," and so on.

The second ran boats of a rather larger and swifter class, which were built by Ditchburn chiefly, and were also engined by Messrs.

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Penn and Sons, and were named "Moonlight," "Starlight," "Daylight," and so on; later followed "Matrimony," "Wedding Ring," etc.

The third ran vessels from London Bridge to the Surrey side of Westminster Bridge. They are said to have been known as the flower boats from their names; "Blue Bell," "London Pride," "Camelia," "Dahlia," etc.

The Citizen and Iron Steamboat vessels ran at fares from twopence upwards, according to distance. They went up river to Chelsea and to Kew. The London and Westminster boats charged one penny per journey.

The fourth ran vessels from Dyer's Hall Wharf near London Bridge to the Adelphi, Strand. They were of 15 nominal H.P. and consumed about 2¼ cwts. of coal per hour. Their hulls were constructed fore and aft ends alike, so as to run either way without turning round. Their engines, with oscillating cylinders by Messrs. Joyce and Co., are said to have been on the compound system, working with high-pressure steam from boilers by Montgomery. Their names were "Ant," "Bee," and "Cricket." The "Cricket's" boiler unfortunately exploded in August 1847, whilst waiting at London Bridge at the busy time of the day. The boats had two rudders, one at each end, which when not required for use were locked fast and formed part of the hull. The "Cricket" is said to have been replaced by the "Sunshine." These halfpenny fare steamers were greatly patronised by the poorer working classes of the metropolis. The "Endeavour," built in 1829 by Maudslay and Field, and engined by them with oscillating engines, ran from Hungerford (Market) to Richmond. This pioneer of Thames river steamers was followed in 1835 by the "Fly," furnished with oscillating engines by Spiller of Battersea.

It is impossible within the compass of this paper to do justice to the many rapid and remarkable strides made in iron-shipbuilding between the years 1850 and 1860, even though attention be confined to paddle-wheel steamers only. Details of many vessels not mentioned but of great importance will be furnished in time it is

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hoped to this Institution. Such information about early paddle-wheel steamers and their performances is greatly wanted. As an instance may be quoted the "Wave Queen," 210 × 15 feet, 80 nominal H.P., designed and built in 1852 by the late J. Scott Russell. Since 1860 a gradual decline of paddle-wheel steamers seems to have set in.

In 1861 the celebrated paddle-wheel Cunard liner "Scotia" was built of iron at Glasgow by R. Napier and Sons. She was 4050 tons burden, 1000 nominal H.P., with side-lever engines having cylinders of 100 inches diameter and 12 feet stroke. She is the last of the Atlantic ocean paddle steamships. In 1871 she was sold, and is now a twin-screw steamship, altered and engined by Laird Brothers. The "Scotia" was preceded by the "Persia," 3,585 tons burden, 1200 nominal H.P., speed $11\frac{3}{8}$ knots per hour, built of iron and engined by R. Napier and Sons in 1856.

The diagonal system for wooden ship building of Messrs. Johns and O. Lang, once called the "lath and plaster" system, was first tried on the Thames about 1834–37 in the construction of the steamers "Ruby," "Red Rover," "City of Canterbury," and others. The composite construction of ships—partly iron and partly wood —was introduced by Messrs. Ditchburn and Mare of Rotherhithe in 1844, in building one of the Waterman Woolwich packets, and in the "Little Western" paddle-steamer. The first iron steam-vessel built on the Thames was the "Daylight" paddle-steamer by Messrs. Ditchburn and Mare, 1838. Messrs. Samuda Brothers and Messrs. J. and G. Rennie in 1857 turned out the first steel-built vessels on the Thames.

The compound expansion engine was first proposed by Jonathan Hornblower in 1776, and in 1804 was improved by Arthur Woolf, by whose name it is still designated. In 1872–73 a powerful set of oscillating engines on the compound system was placed by Messrs. Laird Brothers in a paddle-wheel steamer built by them at Birkenhead.

The "Era" paddle-steamer, 1841, was fitted by Spiller of Battersea with a compound or Woolf engine, having cylinders $17\frac{3}{8}$ and 20 inches in diameter, stroke 20 inches. Mr. Spiller's water-tube boiler supplied steam at 40 lbs. per square inch. A surface

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condenser and steam regenerator, on the system of Mr. Zander, a Swedish engineer, was fitted to the engine. Coke was used as fuel.

As regards steamers employed in the various channel and sea routes around Britain, the screw-propeller is gradually superseding the paddle-wheel. A notable instance is in the fleet of steamers of the Great Eastern Railway now running between Harwich and Antwerp. So late as 1880 a powerful paddle iron steamer, the "Lady Tyler," was built by Messrs. T. and W. Smith, Newcastle, for this service, and was fitted with compound steeple engines by Messrs. R. and W. Hawthorn. Each engine has three cylinders, one of 33 and two of 44 inches diameter, and 5 feet stroke; boiler pressure 70 lbs. per square inch. She has since been rivalled by twin screw-vessels, the "Norwich" and the "Ipswich," built in 1883 by Earle's Shipbuilding Co., Hull, of 1400 tons burden, with engines of 300 nominal H.P. collectively; speed 13 knots per hour.

Home Services.—The various home-services still performed with paddle-steamers are, so far as the compiler knows, as follows:—

Holyhead and Kingstown. In early days the Admiralty fulfilled the mail service. The City of Dublin Steam-Packet Co.'s paddle-steamers: "Leinster," "Ulster," "Munster," and "Connaught," four sister vessels, iron-built in 1860 by Messrs. Samuda Brothers, and Messrs. Laird Brothers, about $348 \times 35 \times 20$ feet; 2039 tons burden, 720 to 750 nominal H.P., speed 21 miles per hour. The engines are oscillating, those of the "Leinster" and "Connaught" by Ravenhill and Co., those of the "Ulster" and "Munster" by Boulton and Watt. The feathering-float paddle-wheels are 34 feet full diameter, each having fourteen floats of 12 feet length and 4 feet depth; their dip is $5\frac{3}{4}$ feet at deep draught. These steamers are now under alteration and improvement by Messrs. Laird. They will be assisted by a new vessel, the "Ireland," steel-built, 380×38 feet, oscillating engines 6000 nominal H.P., speed 20 knots per hour, building at Birkenhead by Messrs. Laird Brothers.

The London and North Western Railway fleet plying between Holyhead and North Wall, Dublin, built of iron. The "Violet"

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and "Lily," built in 1880 at Birkenhead by Laird Brothers, with engines of 3000 indicated H.P., represent their earlier sisters "Rose," "Shamrock," "Eleanor," and others. The newest vessel is the "Banshee," built in 1884 by Laird Brothers, 310 × 34 × 14 feet, 1781 tons, 3500 indicated H.P., speed 19 knots per hour.

The London and South Western Railway service between Southampton and Havre is run by the "Southampton" and other steamers. One of them, the "Wonder," not long since on this station, and for years the fastest steamer from Havre, had powerful condensing engines on Seaward's atmospheric principle of 1850; some time afterwards two larger steamers were also fitted with the same type of engine. These, and the Thames steamer "Sapphire," are the only vessels the compiler is aware of that were fitted with engines on this plan. The engines had three vertical fixed cylinders with open tops, the down stroke of the pistons being consequently due to atmospheric pressure. A small working engine on the same principle was exhibited by Messrs. Seaward in 1855 at the Paris Exhibition, and is now in the Conservatoire des Arts et Métiers.

The Channel Islands service, worked from Southampton and Weymouth, by the South Western and Great Western Railways. The "Normandy," iron-built 1863 by James Ash, Millwall, 210 × 24 × 14 feet, had oscillating engines of 220 nominal H.P. by John Stewart and Co., Poplar, with surface condensers; boiler pressure 22 lbs. per square inch, speed 14½ knots per hour. The "Cygnus," "Aquila," and other paddle steamers are still running.

Milford Haven to Waterford and Cork. Paddle steamers of the Great Western Railway, built by Messrs. W. Simons and Co. of Renfrew in 1877. The vessels are fitted with compound oscillating engines having cylinders 50 and 90 inches diameter with 6 feet stroke, and paddle-wheels 24 feet diameter.

Bristol to Cork and Waterford: information wanting.

Liverpool and Fleetwood to the Isle of Man: worked by the Isle of Man Steam Packet Co., Douglas. The smallest vessel is 518 tons gross. The largest, "Mona's Isle," is 1500 tons gross, and measures 330 × 38 × 15 feet, with 4500 indicated H.P.

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Barrow-in-Furness to Belfast and the Isle of Man. Modern paddle-wheel steamers built of steel in 1880-83, chiefly by the Barrow Shipbuilding Company.

Queenborough and Flushing. A recent service of paddle-steamers started by the Netherlands Zeeland Steamship Company in 1876 with English-built vessels. They have oscillating engines on the compound system. The "Princess Marie," built of iron in 1877 by John Elder and Co., Govan, 1652 tons gross, 600 nominal H.P., is a type of the fleet; she is $278 \times 35 \times 24\frac{1}{4}$ feet. The compound oscillating engines, with boilers, and machinery, are by Elder and Co.

The Folkestone and Boulogne service of the South Eastern Railway, worked for many years now, has been refurnished with modern vessels, of which the "Albert Victor," built in 1880 by Messrs. Samuda Brothers of Poplar and fitted with oscillating engines by Messrs. J. Penn and Sons, is a representative. In 1845–6 the steamer "Prince Ernest," and in 1846–7 the "Lord Warden," and others, 446 tons, 160 nominal H.P., were built by Messrs. Laird for this service.

The Dover and Calais service was carried on by the Admiralty up to 1840 inclusive. Among the earliest mail-boats were the wooden paddle steamers "Ariel," 152 tons, 60 nominal H.P.; "Beaver," 128 tons, 62 nominal H.P.; "Swallow," 133 tons, 70 nominal H.P.; and "Widgeon," 162 tons, 90 nominal H.P. They were followed by iron built vessels, of which the first on the station was the "Dover," by Laird Brothers, 1840; $113 \times 21 \times 9\frac{7}{8}$ feet, 228 tons, 90 nominal H.P. This service is now fulfilled by the London Chatham and Dover Railway and the South Eastern Railway. The "Princess Mary" and "Princess Maud" were built in 1844; the latter, by Ditchburn and Mare, was fitted with Maudslay and Field's vertical engines on the "annular" system of Joseph Maudslay, 120 nominal H.P.; her paddle-wheels were 19 feet 4 inches diameter. The "Princess Alice" had also been fitted with similar engines in 1843. The "Samphire," an old favourite on this station, has diagonal engines by Ravenhill with two oscillating cylinders placed opposite each other on the keel line, driving the cranks on the paddle shafts.

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More powerful and newer vessels of note on this station are the "Maid of Kent," "Wave," "Foam," and "Breeze." A still newer vessel in this service is the "Invicta," built of steel in 1882 by the Thames Ironworks Company, Millwall. Her dimensions are 312 × 33 × 17¼ feet, draught of water 8½ feet, 1647 tons. Her engines by Maudslay and Field are 4000 indicated H.P., and have oscillating cylinders 80 inches diameter with 6½ feet stroke; boiler pressure 30 lbs. per square inch. The "Invicta" has been followed by the "Princess Beatrice."

The Dover and Ostend mail service was also in early days conducted by the Admiralty. It is now performed by the Belgian government with iron-built paddle-steamers of high speed constructed and engined by the Société Cockerill, Seraing, Belgium.

The Newhaven and Dieppe service, worked by the London Brighton and South Coast Railway, beginning with small steamers on account of the bad entrance channel to Newhaven harbour. The newer paddle-wheel vessels employed are the "Brighton" and "Victoria," built of steel in 1878 and engined by John Elder and Co., Govan. Dimensions 220 × 27½ × 11½ feet, 819 tons, engines of 300 nominal H.P.

Channel Service.—In connection with Channel steamers, mention must not be omitted of the attempts which have been made and are still probably under consideration, to prevent the passage from being unpleasant under any circumstances of sea, wind, or weather. The paddle-steamers "Castalia," "Calais-Douvres," and "Bessemer" have been constructed to accomplish this problem.

The "Castalia" was built in 1874 by the Thames Iron Works Company from designs by Captain T. W. Y. Dicey. She had two half-ship hulls, held firmly parallel, with space between them for the paddle-wheels. Her extreme length was 290 feet, extreme breadth 60 feet, draught of water 6 feet. The engines were on the diagonal arrangement. The machinery was constructed by Messrs. J. and A. Blyth and Co. The career of the "Castalia" was neither satisfactory nor enduring; her collective engine power was 260 nominal H.P.

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In 1877 Messrs. Leslie of Hebburn, Newcastle, built another double-hull vessel, at first called the "Express," but now known as the "Calais-Douvres." She differed from the "Castalia" in having two complete hulls, which, though separated, were kept together parallel to each other by strong wrought-iron girders. She is 300 × 60 feet, and has engines of 4000 indicated H.P. The paddle-wheels are placed between the two hulls. She commenced duty in May 1878, and has kept her station since between Dover and Calais in the service of the London Chatham and Dover Railway. The steamer "London Engineer," 70 nominal H.P., built and engined in 1818 by Messrs. Maudslay and Field, is an early example of a vessel with centre paddle-wheel.

The "Bessemer" paddle-steamer, iron-built at Hull by Earle's Shipbuilding Co., was launched in 1875. She had a complete ship's hull, and in the centre of her length was slung a large swinging saloon, controlled by hydraulic arrangement and skilled labour, so as to keep the saloon always on the level irrespective of the movements of the ship's hull. The saloon and apparatus were designed by Sir Henry Bessemer. The ship was tried at sea in January 1875, and obtained a speed of 19 to 20 miles per hour. She had four paddle-wheels, two on each side of her hull, fore and aft, thus reverting to the plan of Bell's "Comet" of 1811; there were two sets of engines for each pair of wheels. The vessel was 350 feet long, by 40 feet beam. Her engines, by Earle's Co., were 4000 indicated H.P. collectively. Both pairs of feathering-float wheels driven by them were 30 feet in diameter, and were placed 106 feet distant from each other fore and aft.*

Saloon Steamers.—The class of paddle-steamers known as saloon-steamers is due to America. The saloon, or passenger accommodation entirely on the upper deck, has long been in vogue in the United States and Canada; but here the plan was not taken up until 1863,

* A full description of this steamer is given in a paper read to the Institution of Naval Architects in March 1875 by Sir Edward J. Reed, K.C.B., M.P.

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when the "Iona" paddle-steamer on the Clyde was constructed by Messrs. J. and G. Thomson, of Govan and Glasgow, for the Scottish tourist service of Messrs. D. Hutchinson and Co. The "Iona" is 245 × 25 × 9 feet; draught a little over 4 feet. Her engines by Messrs. J. and G. Thomson have oscillating cylinders 46 inches diameter with 4 feet stroke; they make 42 revolutions per minute, equal to a piston-speed of 336 feet, and drive paddle-wheels 20 feet diameter. On the upper deck is a saloon of 180 feet total length, the top of which forms a promenade. The "Iona" has been followed by a larger vessel on the same plan, called the "Columba."

Saloon-steamers were introduced on the Thames in 1866. The two first were the "Albert Edward" and "Princess Alice," built for service on the Clyde by Messrs. Caird and Co. of Greenock. The "Princess Alice" was 219½ × 20 × 9½ feet, 251 tons, 140 nominal H.P. On 3rd September 1878 she was totally lost in the Thames by collision with the screw-steamer "Bywell Castle."

Stern-wheel Steamers.—These seem never to have taken firm root in England. A few are working on our canals as tow-boats only. In 1878 Messrs. Yarrow and Co., Poplar, turned their attention to this class of steamer for the navigation of the shallow rivers of South America. The "Inez Clarke," 130 × 28 feet, with a draught of only 15 inches and a speed of 15 miles per hour, is an example of modern stern-wheel propulsion. The stern-wheel is driven by high-pressure compound horizontal engines, having cylinders about 15 and 27 inches diameter, with 4½ feet stroke. The boiler is of locomotive type, and supplies steam at 120 lbs. per square inch. The engines are placed right aft, whilst the boiler is right forward, to secure balance and even keel to the vessel in working. Mr. Morey, U.S.A., experimented in America with oars and wheels, particularly with stern wheels, 1790 to 1797.

Another paddle-wheel steamship to be referred to on this occasion is the "Great Eastern," iron built in 1857 on the Thames by the late John Scott Russell from designs by Brunel. Length over all 692 feet; breadth 83 feet; depth, upper deck to keel, 60 feet.

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Immersed depth light 15½ feet; at full load 30 feet. Displacement when loaded 27,384 tons; cargo and fuel space 16,000 tons. The launching at Millwall, broadside on to the Thames, lasted from 3rd November 1857 to 31st January 1858. The ship was propelled by both paddle-wheels and a screw-propeller. The paddle engines designed by Mr. Scott Russell in 1853 had four oscillating cylinders working diagonally (two and two) on the main-shaft cranks. They were 1000 nominal H.P. The cylinders were each 74 inches diameter with 14 feet stroke, making 14 revolutions per minute. They formed two distinct engines, and had each their own air-pumps, condensers, and other needful accessories. Each cylinder, cast in one piece, weighed 28 tons. The condenser weighed 36 tons. The upper frames of the engines, cast in four pieces, weighed 13 tons. The intermediate crank-shaft was 26 inches diameter and 22 feet long, with main cranks 7 feet long between centres; it weighed 30 tons, and was made by Messrs. Fulton and Neilson, Lancefield Forge, Glasgow. The total weight of the paddle-shaft was 80 tons. The diameter of the paddle-wheels was 58 feet, equalling an advance of 60 yards in one revolution. They could be disconnected from or coupled to the engines at will. The screw engines on the horizontal arrangement were by Watt and Co., Soho, Birmingham; 1600 nominal H.P. They had four cylinders placed opposite each other, driving the main shaft; diameter of cylinders 84 inches, stroke 4 feet. The four-bladed screw-propeller was 24 feet diameter and weighed 36 tons. The average steam pressure in the ten main boilers was 20 to 25 lbs. per square inch. The ship is built on the cellular system, and has two skins with space between of 2 feet 10 inches; twelve water-tight compartments, and seven partially so; two longitudinal bulkheads 60 feet high, 350 feet long, 36 feet apart. Floor plates or keel 1 inch thick; inner and outer skin plates ¾ inch; bulkheads ½ inch thick. Speed on trial 14½ knots or about 17 miles per hour. Though remarkable as being the largest iron-built vessel ever constructed, it is understood that the ship is now practically laid aside; consequently she may become entirely forgotten.

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Hydraulic or Water-Power Propulsion.— Water forced out by pumps and a steam-engine, along sides or at stern of a boat. Ramsay or Rumsey, U.S.A., proposed this method of propulsion, carrying out a series of experiments in America from 1784 to 1793, and afterwards in London in 1805 with James Watt. Messrs. Ruthven of Edinburgh took up the same idea again in 1843. In 1866 a small boat called the "Nautilus" was fitted out for testing Mr. D. Ruthven's improved arrangements and proposals of 1849. She proved herself worthy of further trial and development: which at length culminated in the application by the Admiralty of the hydraulic or water-power system in 1866 to H.M. armour-plated ship "Waterwitch," of 778 tons burden, built by the Thames Iron Works Company, Millwall, with engines of 160 nominal H.P. by Messrs. J. and W. Dudgeon of Blackwall, driving a centrifugal pump. The pump had a horizontal fan or turbine wheel 14$\frac{1}{3}$ feet diameter, by which the water fed to it through perforations in the vessel's bottom was forced out with great velocity through pipes laid fore and aft along the ship's sides, on the line of her flotation. The direction given to the water jet from the pump by means of valves caused the ship to go ahead or astern without any alteration in the motion of the engines.

John Allen, M.D.,—author of "Specimina Iconographica," London, 1730,—had proposed the water-jet mode of propulsion in 1730. A pump or other means was to be employed for projecting a driving stream of water from the vessel.

There have been seen working on the Thames from time to time some curious schemes for driving small steamers. Particulars about these would be very interesting and instructive.

The "Locomotive," about 1840, a paddle-steamer working up the river to Richmond and Hampton Court. She was iron-built, by Ditchburn, and fitted by Braithwaite and Milner entirely on the plan of the locomotive high-pressure boiler and engine. The exhaust was carried direct into the boiler funnel, causing the locomotive beats; hence the boat's name. She was followed by the

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"Cardinal Wolsey," fitted with a single direct-acting engine by the same makers, and for the same service.

The "Propeller," about 1845, an iron vessel driven by two huge dash-boards in lieu of paddle-wheels. These dash-boards were driven with the walking action of a "daddy long-legs" or spider, by means of levers connected with the engines, which also drove the boards reversely as required, so as to obtain "ahead" or "astern" motion of the vessel. The "Propeller" ran between Greenwich and Blackwall, but did not enjoy a long or successful career.

A small boat driven by a huge dash-board at the stern, which was thrust into the water by a pair of engines through rocking levers, was persevered with for a long time, but it seems never to have attained practical value.

It appears that from 1783 to 1791 Mr. Fitch, an American inventor, had experimented with his proposals to propel a vessel by means of shovels driven or worked by a steam-engine. In 1791 he tried to introduce his plans into France.

American Beam-Engines.—The American plan of driving paddle-wheel steamers by a single powerful beam-engine has never met with favour in Britain. The steamers "North America" and "New World" are types of these American vessels. The "New World" was built in 1849 and engined in 1850 by T. F. Secor of New York. She was 376 feet long, 36 feet beam, 10½ feet depth of hold. She had a single engine, with the frame of wood, and a cast-iron skeleton beam trussed with wrought iron, 26 feet long by 26 inches deep at main centre. The connecting-rod to the crank was also of iron and trussed. The cylinder was 76 inches in diameter, with a stroke of 15 feet, and made 18 strokes per minute. The paddle-wheels were 45¼ feet in diameter, the floats 11¾ feet long by 3 feet deep. The steam pressure in the boilers 30 to 35 lbs. per square inch; 6000 lbs. of anthracite coal was burnt per hour. The speed of the "New World" was as much as 20 miles per hour. The steamers on the river Hudson are usually fitted with condensing engines, whilst those on the Mississippi have chiefly non-condensing

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engines. Messrs. A. and J. Inglis of Pointhouse, Glasgow, have recently furnished a fleet of iron steamers for service in China, mostly engined with a single beam-engine. The "Hankow" built in 1873, the "Ho-Nam" and the "Kiang-Yu" built in 1882, are three of their vessels. The "Hankow" is 308 × 42 × 15¾ feet, gross tonnage 3073. The engine cylinder is 72 inches in diameter, stroke 14 feet. The wheels are 38 feet in diameter. The vessel's speed is 13 knots per hour. The "Ho-Nam" was fitted with a beam engine on the compound system, having two cylinders at one end of the beam. The "Kiang-Yu" with others was fitted with compound diagonal engines. In 1884 two sister vessels, the "Saturno" and "Olympo," were completed by Messrs. Inglis for service on the river Plate, South America. Each was 286 × 34 × 12 feet, and was fitted with a compound beam-engine having two cylinders at one end of the beam; the speed on trial averaged 15½ knots per hour.

Tugs.—Paddle-wheel steamers for towing purposes still continue to be built for sea and river service all round our coasts. The following paddle tugs are mentioned as representing this class of paddle steamer.

The "Paul," built by Messrs. Laird Brothers at Birkenhead in 1880–81, 130 × 25¾ × 15¼ feet, was fitted with two sets of independent engines, which could be connected or disconnected and worked separately at will. They were on the compound system with inclined oscillating cylinders, each set of engines having two cylinders of 28½ and 48 inches diameter and 5 feet stroke; collective power 941 indicated H.P.; working steam pressure 60 lbs. per square inch. Speed 10·9 knots per hour.

The "Albatross," built at South Shields by Messrs. Hepple and Co.; 140 × 19 × 8¼ feet. Lever engines of 53 nominal H.P. Speed 13 knots per hour.

The "Mount Etna," built in 1880 by Mr. R. Chambers, Dumbarton; 145 × 21½ × 13½ feet. Engines by Messrs. Rankin and Blackmore of Greenock, with compound inclined cylinders of 25 and 48 inches diameter and 5 feet stroke; working steam pressure 70 lbs. per square inch.

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The largest paddle-wheel tug recently completed is perhaps one built in 1884 by Messrs. Alley and MacLellan of Glasgow, 260 × 35 × 10 feet, with two pairs of McGregor's design of paddle engines indicating 1000 H.P.

At Belfast there was completed in 1882 by Messrs. MacIlwaine and Lewis, the paddle steamer "Monkstown," 140 × 16 × 8 feet. She was fitted with oscillating engines; and with her sister, the "Albert," is employed for service at Cork.

Steam Ferries.—The well known ferry steamers plying across the river Mersey to and from Liverpool may be recorded as a special type of paddle-wheel steamer. They are iron-built, having both ends alike, and run at equal speed either end first. The "Cheshire," one of the earliest, 150 × 30 × 12 feet in hull, 48 feet extreme width, 130 nominal H.P., was built in 1863 at Liverpool by Messrs. Hill, Lawrence and Co., from designs by the late Mr. C. Harrison, nd has been followed by several similar steamers. On the Thames a scheme was started in 1876 for a service of steam ferry boats across the river below London Bridge. Two paddle steamers were put on duty, the "Jessie May" and the "Pearl," about 85 × 42 × 9 feet, 30 nominal H.P., working with steam at 35 lbs. per square inch. They ran either end first, and were designed to carry simultaneously horsed vehicles and cattle, as well as passengers. Owing to many difficulties this ferry was ultimately given up.

Steam Trawlers.—Another useful application of paddle-wheel steamers is as steam-trawlers in the North Sea fishery. The "Flying Dutchman," built in 1880, the "Flying Fish," built at Sunderland in 1882, of 90 nominal H.P., and the "Constance," built at South Shields in 1882 by Mr. Eltringham, with engines of 40 nominal H.P., represent a recent and special class of modern steam fishing-craft.

In conclusion, it may perhaps be safely predicted that there still remains for the paddle-wheel a prolonged career of useful service.

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Patents for Paddle-Wheels.

Thomas Savery . .	1697–8.
Jonathan Hulls . .	1736.
Patrick Miller . .	1787.
John Morgan . .	1812.—Feathering wheels.
Charles Baird . .	1815.—Feathering wheels.
John Oldham . .	1820.—Feathering wheels.
James Seaward . .	1825 to 1841.—Feathering wheels.
E. Galloway. . .	1829.—Feathering wheels.
J. Spurgin . . .	1837.—Chain wheels.
Joshua Field . .	1838.—Cycloidal wheels.
G. Rennie . .	1839.—Float-boards and paddle-wheels.
D. Napier . . .	1841.—Feathering wheels.
J. J. Brunet . .	1843.—Reefing wheels.
H. Maudslay . .	1843 to 1846.—Feathering wheels.
W. C. Golling . .	1865.—Feathering wheels.
J. J. Aston . . .	1875.—Disc wheels.
McLellan and Owen .	1882.—Canal-boat wheels.

There are about four hundred patents for paddle-wheels down to 1882.

Discussion.

Mr. F. W. CROHN, drawing attention to an admirable model of the stern-wheel steamer "Inez Clarke," which was kindly exhibited by the builders, Messrs. Yarrow and Co., mentioned that the model was exactly like the stern-wheel steamers which that firm were now building for the English war office for work on the Nile. Two such steamers had already been constructed, and five more were in course of construction.

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Mr. HENRY MAUDSLAY thought it would be well to record the fact that, in order to balance many of the forms of oscillating and reciprocating engines used in connection with paddle-wheels, iron floats had been put on the paddle-wheels in such positions as to balance the cranks of the engines.

The PRESIDENT said the paper was entirely historical, and there could hardly be occasion therefore to discuss it; but that was no reason why they should not pass a hearty vote of thanks to the author for having brought the subject forwards in so elaborate a way. He was sure the members would agree with him that it was a valuable addition to their Proceedings to have such a history of paddle-wheel navigation from the very earliest period.

The vote of thanks was unanimously agreed to.

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MEMOIRS.

GEORGE CLARK was born at Fatfield in the county of Durham on 25th September 1815. After having served his apprenticeship partly at his father's works in Sunderland and partly at the Bishopwearmouth Iron Works, he worked for two or three years in various parts of the country, gaining experience. About 1840 he joined his eldest brother and others in the firm of Messrs. John Clark and Co., Sunderland, with whom he remained some three or four years, during which time he was employed principally in erecting engines for drainage in Cambridgeshire, and pumping and winding engines for collieries and ironworks in Durham and other districts. On dissolution of partnership of the above firm, he was for a short time manager of some small works in Sunderland; after which he was engaged as engineer at the Consett Iron Works for seven or eight years. He then returned to Sunderland, and commenced on his own account a business which proved very successful, necessitating removals twice to new premises. The last of these, the Southwick Engine Works erected in 1872, which are large and well situated for the purposes of marine-engine building, were visited on his invitation by the members of the Institution in the excursion to Sunderland on the occasion of the Newcastle meeting in 1881. From an early age he was afflicted with severe asthma, which interfered very greatly with his attention to business; and during the last few years he was unable to take a very active part in it. His death took place on 15th January 1885 at the age of sixty-nine, at his residence, Oak Lea, Sunderland. He was the builder in 1851 of the first iron ship built on the river Wear, an iron sailing ship named the "Loftus," and also of the first marine engines built there; and his energy and enterprise did much to develop the marine-engine business in Sunderland. He became a Member of the Institution in 1859.

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John Holliday was born at Handsworth, Birmingham, on 24th May 1825. He acted in the capacity of manager of the tar works of Messrs. John Bethell and Co., Westbromwich, Mr. Bethell being the inventor of the process so generally in use of creosoting timber for railway and other purposes. He superintended the erection and working of various creosoting establishments both in this country and on the continent. After Mr. Bethell's decease he continued with the firm, until his service of thirty-five years was closed by his own death, which took place after a long illness on 19th January 1885, at the age of fifty-nine. He became a Member of the Institution in 1865.

Thomas Kirkwood was born at Southampton on 30th April 1850, being the second son of the late Mr. Thomas Kirkwood, of the firm of Messrs. Kirkwood and Turner, engineers, Malta. After serving his time for two years in the machine works of Messrs. Crawhall and Campbell, Glasgow, and for four years in the works of Messrs. R. Napier and Sons, Glasgow, he entered the service of the Royal West India Mail Co. as sea-going engineer. In 1874 he went out to China, and was chief engineer of various steamers in the China Seas. He also superintended the building and engining of a composite paddle river-steamer and a tug steamer, and the rebuilding of the steam-ship "Albay" in Hong Kong, for Messrs. Russell Sturgis and Co., Manila. In 1879 he became harbour engineer of the Hong Kong and Whampoa Dock Co., Hong Kong; and this position he retained until his death, which took place at Hong Kong on 29th August 1884, at the age of thirty-four. He became a Member of the Institution in 1882.

Isaac Slater was born near Wirksworth, Derbyshire, on 15th April 1819. His father was a hand-loom weaver, and had a good trade until the introduction of steam-power, when it fell off in consequence of his having no capital for erecting an engine. On his father's death, the family being left to their own resources, he devoted his leisure time to self-instruction, not having the benefit of more than a few months' schooling. He found employment on the

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railways, as that mode of locomotion came into use; and moved from town to town, each time rising in rank, until he became carriage superintendent of the London and North Western Railway, at the then head offices at Saltley, Birmingham. That post he held for only a few months, and then removed to Gloucester, having been appointed first general manager of the Gloucester Wagon Works, stated to be the first concern to carry on manufacturing operations under the provisions of the limited liability acts. This position he occupied for a quarter of a century, having relinquished it only just before his death, which took place on 6th March 1885, in his sixty-sixth year. In 1874 he was elected first sheriff of the extended city of Gloucester, and in the following year was made a city magistrate and a charity trustee. He was also Russian vice-consul. He became a Member of the Institution in 1859.

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Institution of Mechanical Engineers.

PROCEEDINGS.

April 1885.

The Spring Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Thursday, 30th April 1885, at Half-past Three o'clock p.m.; Jeremiah Head, Esq., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following thirty-eight candidates were found to be duly elected:—

MEMBERS.

William Henry Bailey,	Manchester.
William Barrie,	Yokohama.
Charles Lowthian Bell,	Middlesbrough.
Benjamin Brown,	Widnes.
John Close, Jun.,	York.
Evence Coppée,	Brussels.
Edward John Mines Davies,	London.
Edward Houtson Elsworthy,	Bombay.
Edward Fletcher,	Manchester.
Hector Foster Fourny,	Hull.
Robert James Hatton,	London.
Thomas Hicken,	Rugby.
John Needham Longden,	London.
John William Mackenzie,	Cheadle.

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HENRY DICKENSON MARSHALL,	Gainsborough.
JENNER GUEST MARSHALL,	Bristol.
HARRY WILLIAM MILLER,	Pretoria.
HAROLD MORSE,	Pernambuco.
RICHARD OLIVER ORMEROD,	London.
LIONEL PHILLIPS,	Bultfontein.
OLIVER PUDAN,	Kosloff, Russia.
ROBERT SCOTT,	Tokio, Japan.
ALFRED SHUTTLEWORTH,	Lincoln.
FRANK SHUTTLEWORTH,	Lincoln.
GEORGE WILLIAM SIVEWRIGHT,	West Hartlepool.
WILLIAM HOOPER SLIGHT,	Whitehaven.
PATRICK STEWART-HAMILTON,	North Shields.
WILLIAM TIJOU,	London.
FRANÇOIS TIMMERMANS,	Couillet, Belgium.
JOHN TURNBULL, JUN.,	Glasgow.
WILLIAM HENRY VAUGHAN,	Manchester.
FRANCIS WILLIAM WILLCOX,	Sunderland.
GEORGE JOPE YEO,	Shanghai.
GEORGE FRIEDRICH ZIMMER,	London.

GRADUATES.

LESLIE EVERITT CLIFT,	Manchester.
GEORGE BELLAMY CLIFTON,	Swindon.
CHARLES MUDIE,	London.
PHILIP EDWARD RIPLEY,	Ipswich.

The PRESIDENT said that, in accordance with the notice given in the circular announcing the present Meeting, a professional Accountant had now to be appointed for auditing the accounts of the Institution for the present year: the appointment to be made and the remuneration to be fixed by the vote of the Members now present. He should be glad therefore to receive any nomination for this important office.

On the motion of Mr. JOHN G. MAIR, seconded by Mr. FREDERICK COLYER, it was unanimously resolved that Messrs. Robert A.

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McLean and Co., chartered accountants, 1 Queen Victoria Street, London, by whom the accounts had been audited for the past seven years, be appointed to audit the accounts of the Institution for the present year, at a remuneration of Ten Guineas, the same as heretofore.

The following Paper was then read and discussed:—

Description of the Maxim Automatic Machine-Gun; by Mr. HIRAM S. MAXIM, of London.

At Half-past Five o'clock the Meeting was adjourned till the following evening. The attendance was 84 Members and 79 Visitors.

In the evening the Annual Dinner of the Institution was held at the Criterion, Piccadilly, the President occupying the chair, and was largely attended by the Members and their friends.

The ADJOURNED MEETING of the Institution was held at the Institution of Civil Engineers, London, on Friday, 1st May 1885, at Half-past Seven o'clock p.m.; JEREMIAH HEAD, Esq., President, in the chair.

The following Papers were read and discussed:—

Abstract of Results of Experiments on Riveted Joints, with their applications to practical work; by Professor ALEXANDER B. W. KENNEDY, Honorary Life Member.

Description of a Blooming Mill with Balanced Top Roll at the Ebbw Vale Works; by Mr. CALVERT B. HOLLAND, of Ebbw Vale.

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On the motion of the President a cordial vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated. The attendance was 50 Members and 66 Visitors.

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AUTOMATIC MACHINE-GUN.

Plate 19.

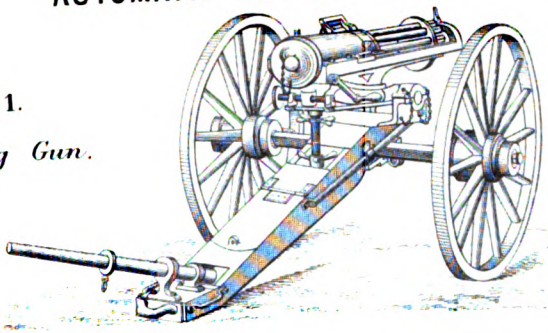

Fig. 1.
Gatling Gun.

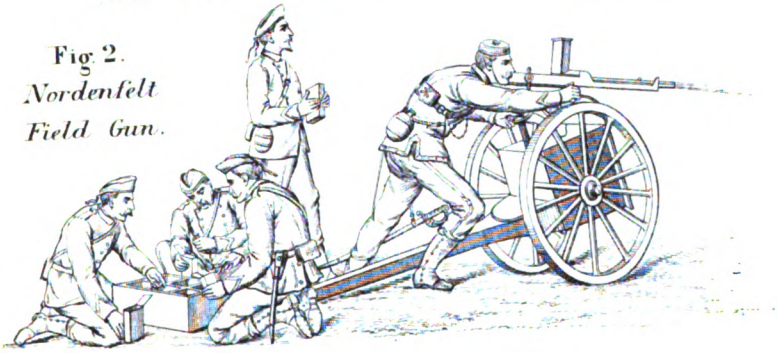

Fig. 2.
Nordenfelt Field Gun.

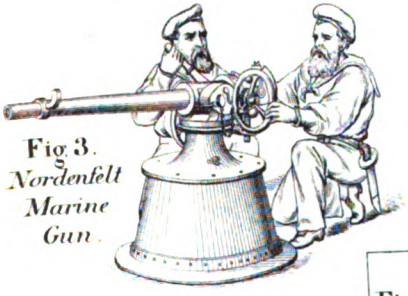

Fig. 3.
Nordenfelt Marine Gun.

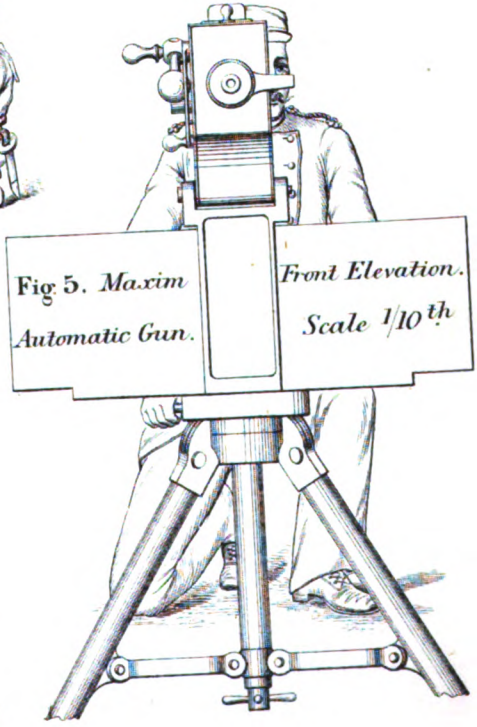

Fig. 5. *Maxim Automatic Gun.*
Front Elevation.
Scale 1/10th

Fig. 4.
Gardner Gun.

(Proceedings Inst. M. E. 1885.)

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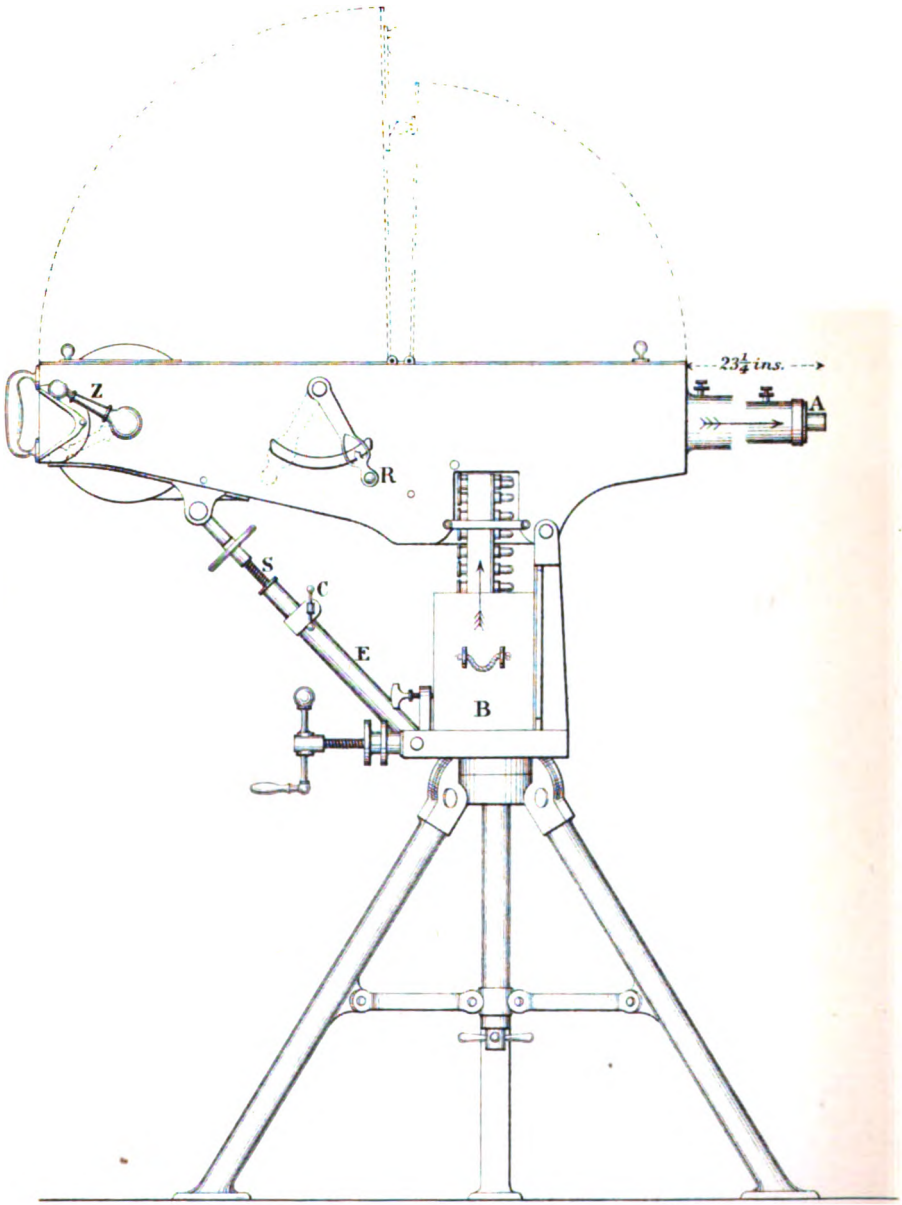
Digitized by Google

Fig. 6. *Side Elevation of Maxim Gun.*



(Proceedings Inst. M. E. 1885.) *Scale 1/10th*

Ins. 12 6 0 1 2 Feet

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AUTOMATIC MACHINE-GUN.

Fig. 7. *Longitudinal Section in position of firing.*

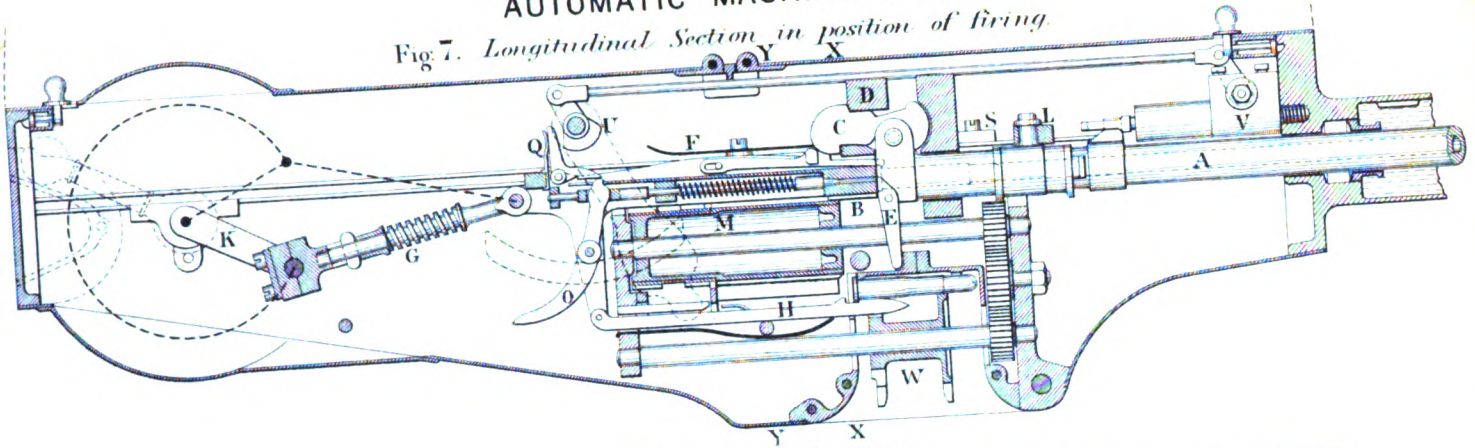
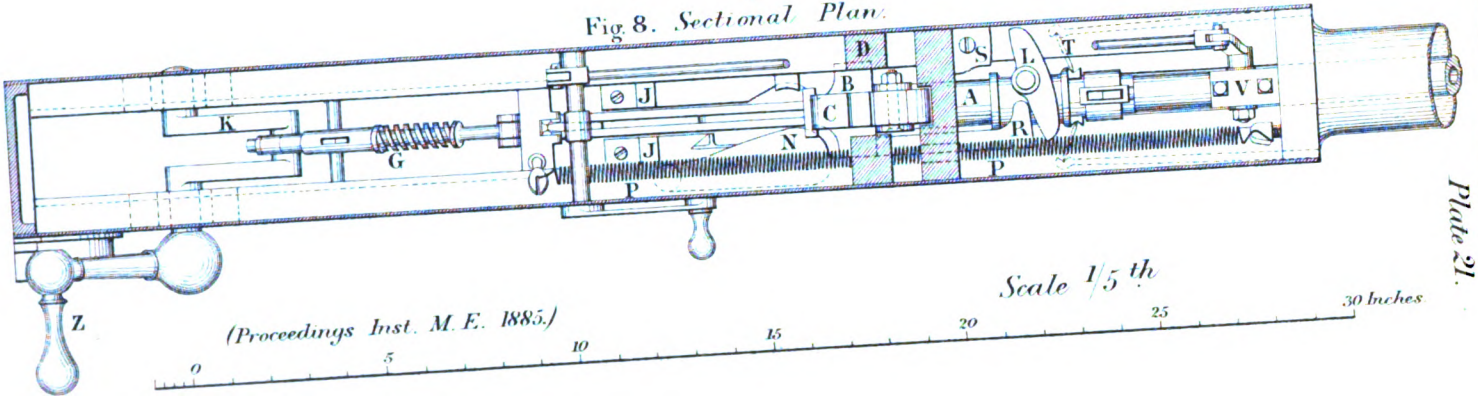


Fig. 8. *Sectional Plan.*



Scale 1/5th

0 5 10 15 20 25 30 Inches

(Proceedings Inst. M.E. 1885.)

Plate 21.

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AUTOMATIC MACHINE-GUN.

Fig. 9. *Longitudinal Section showing Breech-Block fully back.*

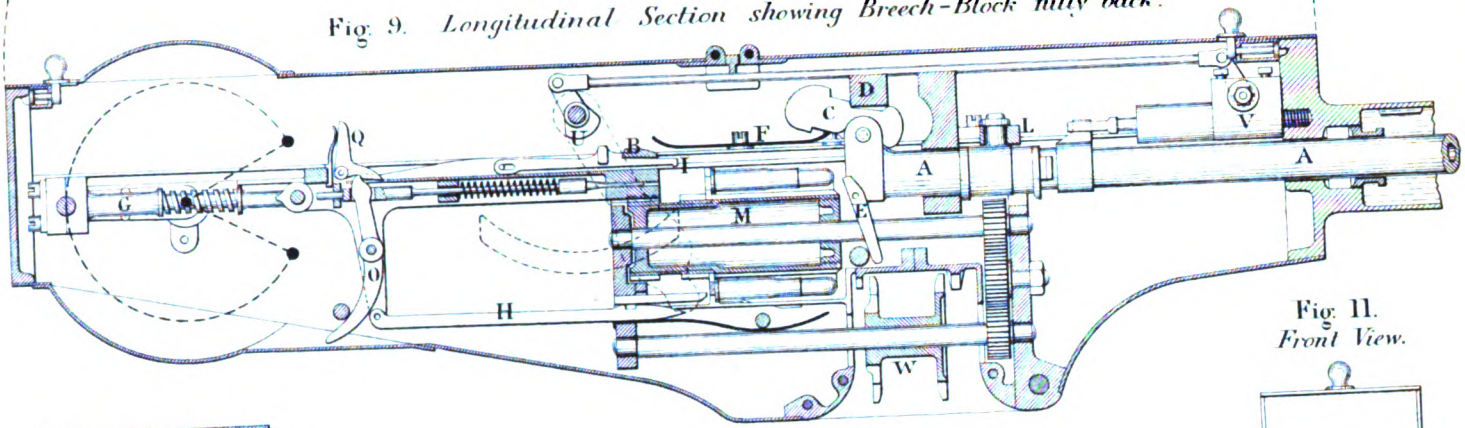
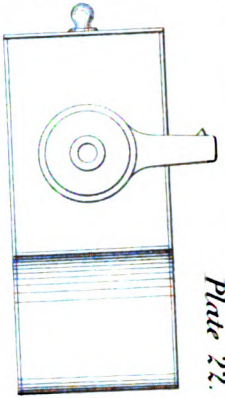


Fig. 11.
Front View.



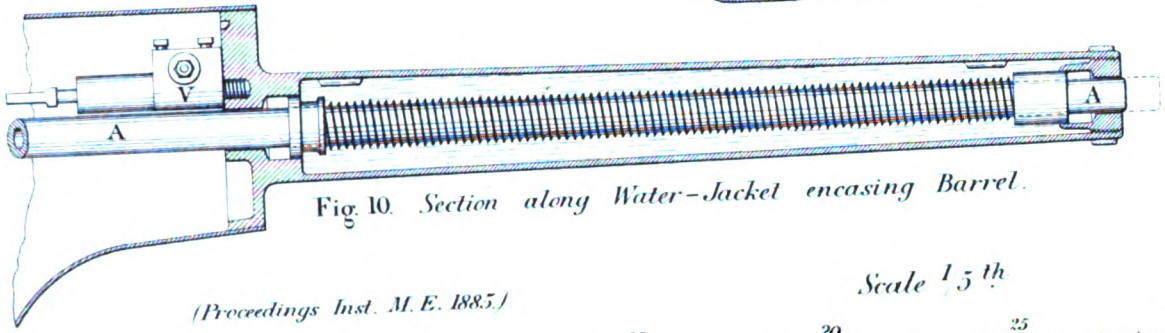


Fig. 10. *Section along Water-Jacket encasing Barrel.*

(Proceedings Inst. M.E. 1885.)

Scale 1/5 th

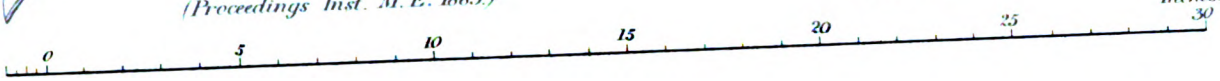


Plate 22.

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Plans showing action of Transfer Lever.

Fig. 12.

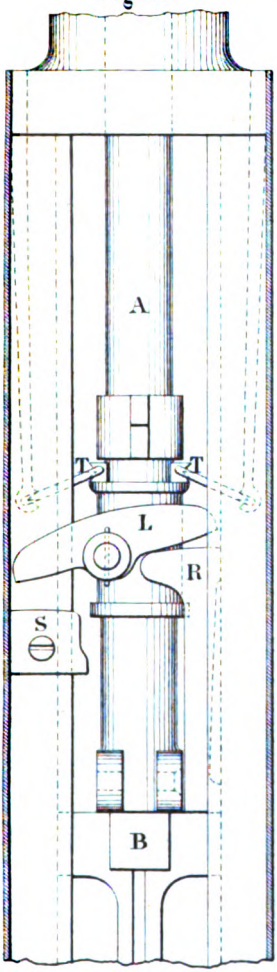


Fig. 13.

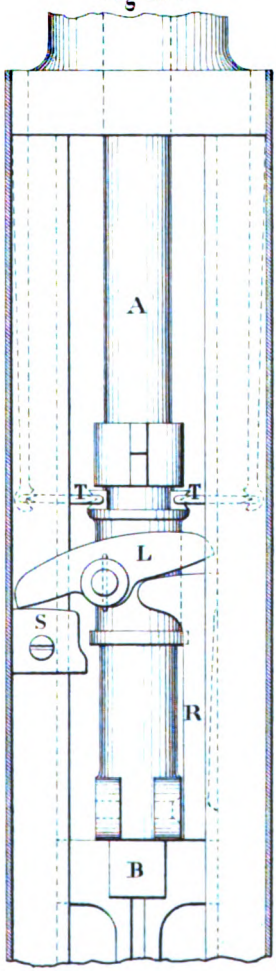


Fig. 14.

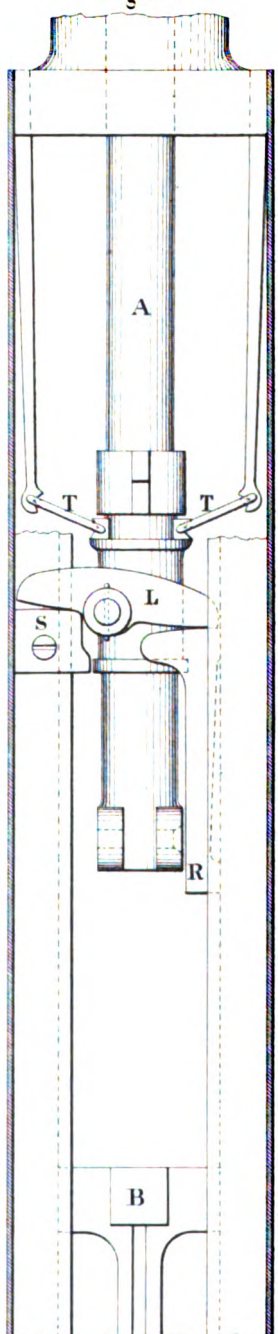
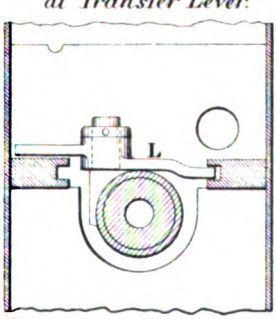
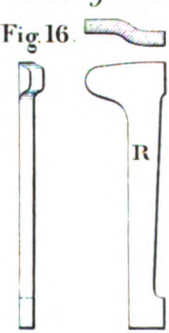


Fig. 15. *Transverse Section at Transfer Lever.*



Striking Bar.

Fig. 16.



(Proceedings Inst. M. E. 1885.)

Scale 1/3rd.

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AUTOMATIC MACHINE-GUN.

Plate 24.

Fig. 17. *Section at XX (Fig. 7) looking from breech.*

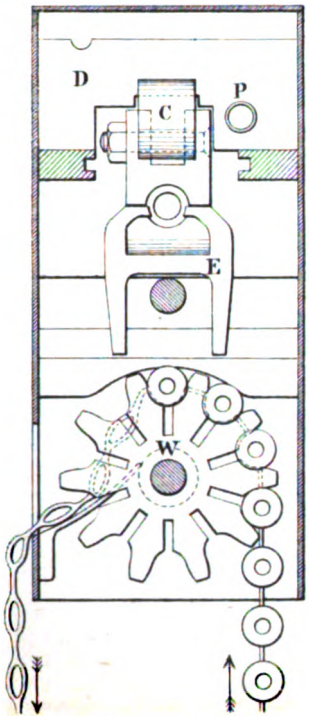


Fig. 18. *Section at XX looking from muzzle.*

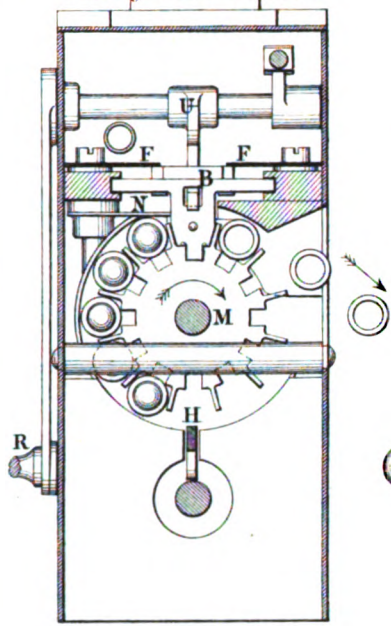


Fig. 19. *Section at YY (Fig. 7) looking from muzzle.*

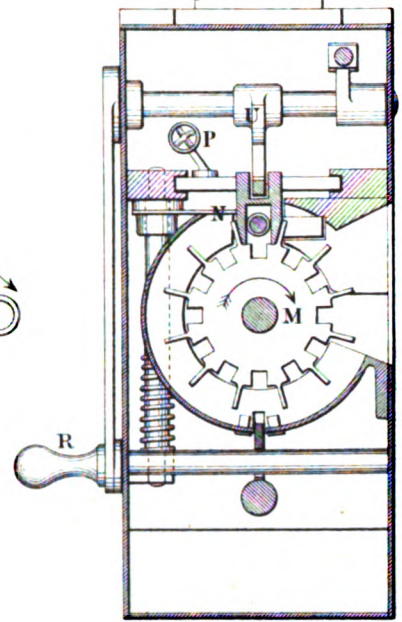
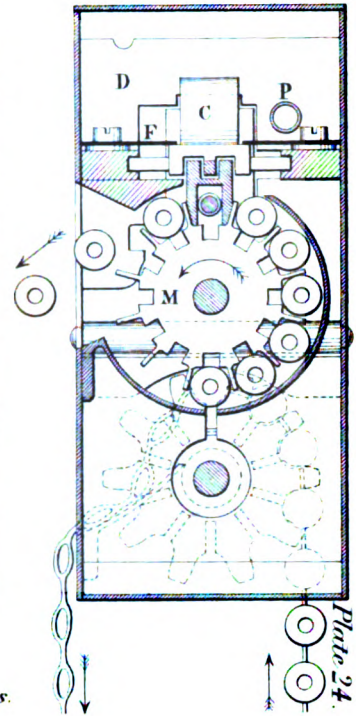


Fig. 20. *Section at YY looking from breech.*



(Proceedings Inst. M. E. 1885.)

Scale 1/3rd

0 5 10 Inches.

Plate 24.

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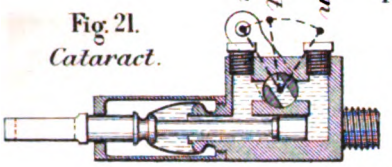
AUTOMATIC MACHINE-GUN.

Plate 25.

Fig. 21. *Cataract.*



Scale 1/3rd

Fig. 22. *Transverse Section.*

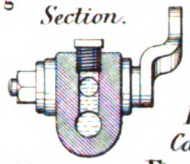
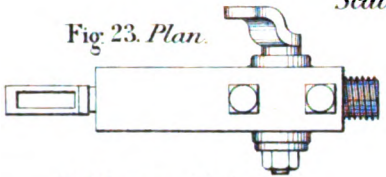


Fig. 23. *Plan.*



Full size Section.

Fig. 24.

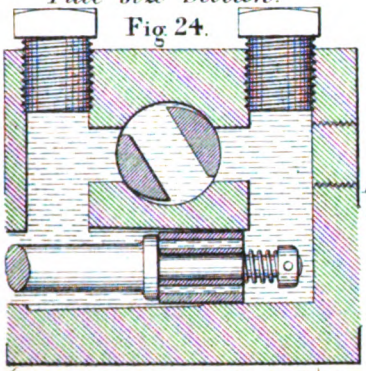
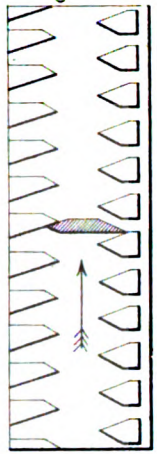


Fig. 25. *End View of Piston.*

(Proceedings Inst. M. E. 1885.)

Spiral Ratchet-Wheel developed flat.

Fig. 28.



Belt of Cartridges.

Fig. 26. *Plan.*

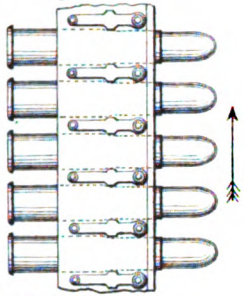


Fig. 27. *Section.*

Pivoted Cover-Plate.

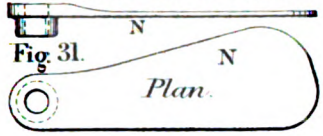


Fig. 31. *Plan.*

Fig. 29. *Extracting Hook on Breech-Block.*

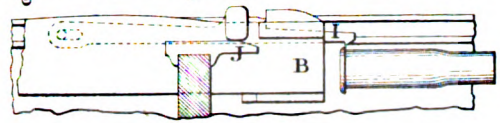
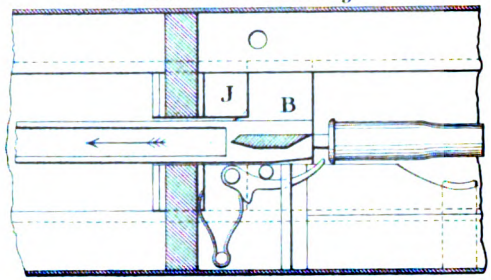


Fig. 30. *Inverted Plan showing Stop for extracted Cartridge-case.*



Extracting Lever on Barrel.

Fig. 32.

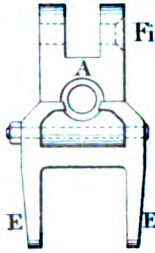
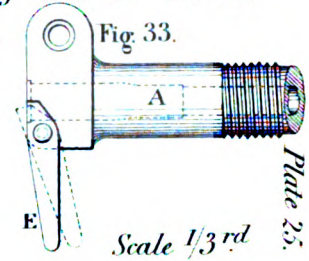


Fig. 33.



Scale 1/3rd

Plate 25.

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AUTOMATIC MACHINE-GUN.

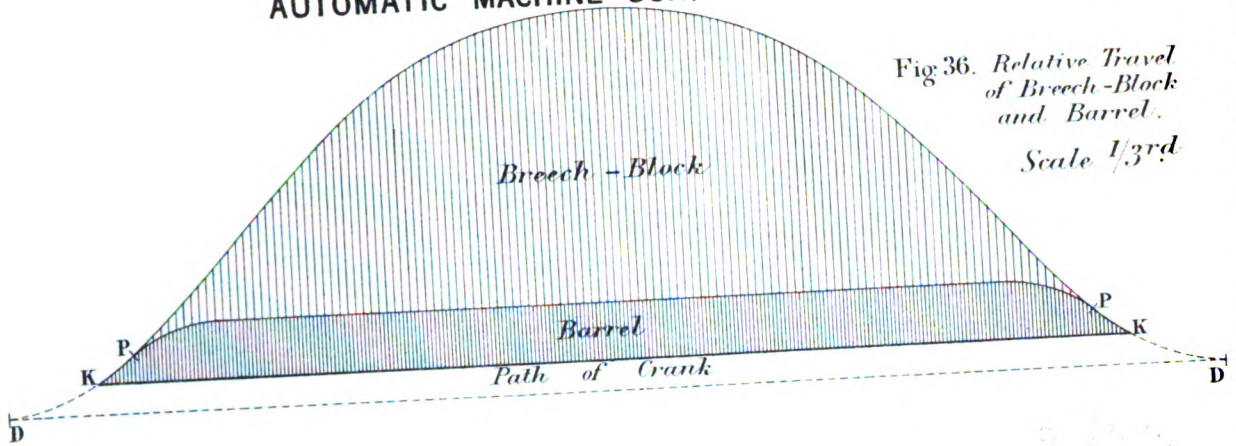

Fig. 36. *Relative Travel of Breech-Block and Barrel.*

Scale 1/3rd

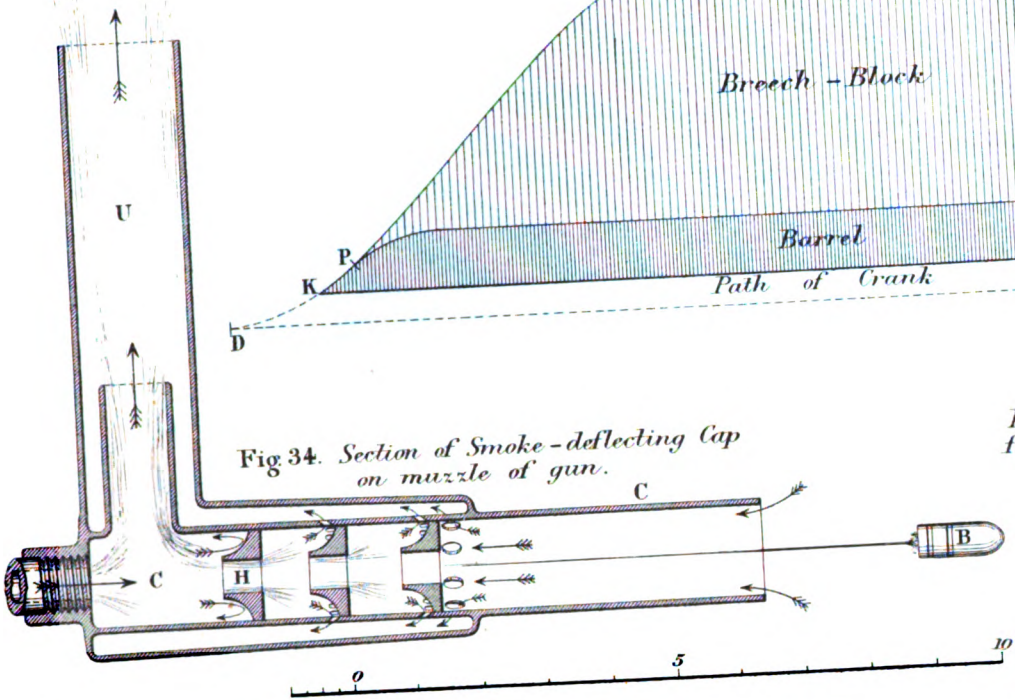

Fig. 34. *Section of Smoke-deflecting Cap on muzzle of gun.*

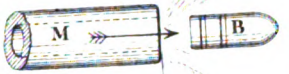

Fig. 35. *Escape of Smoke from gun muzzle.*

Scale 1/3rd

(Proceedings Inst. M.E. 1885.)

Plate 26.

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DESCRIPTION OF THE MAXIM AUTOMATIC MACHINE-GUN.

By Mr. HIRAM S. MAXIM, of London.

Previous Machine-Guns.—The first practical Machine-Gun is believed by the writer to be that made by Dr. Gatling, an American inventor, by whom it was presented to the United States government about 1863. It is shown in general elevation in the accompanying sketch, Fig. 1, Plate 19. In its earliest form it was not made for firing metallic cartridges, but was constructed with a series of steel sections, which, after having been previously loaded by hand, were one after another brought up to the breech of the barrel and pressed firmly against it at the instant of firing. None of the Gatling guns however appear to have been actually used in the field before the close of the American war in 1865. The next machine-gun of any note was that of Hotchkiss, another American inventor, who took it to France, where he established a large factory, and has supplied his guns to nearly all the principal governments in the world. This gun was followed by the Nordenfelt and the Gardner, shown in general elevation in the sketches, Figs. 2 to 4, Plate 19.

All four of these machine-guns depend upon hand power for performing the various operations of loading, firing, and extracting the empty shells. Three of them are worked by a crank, while the Nordenfelt gun is worked by means of a lever, like an ordinary pump. As considerable force is required for working either the crank or the lever, the gun has to be mounted on a very firm stand or base, in order that it may not be rendered unsteady by the motion given to the handle. This necessity precludes the possibility of turning these guns with any degree of freedom: excepting the Hotchkiss gun, which is essentially a slow-firing gun, firing only about forty shots per minute, and is the only one that can be moved freely while firing.

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These guns are each provided with a magazine of ammunition. The Hotchkiss magazine holds about a dozen cartridges; and the quick-firing Gatling, the Nordenfelt, and the Gardner, have each a magazine holding about a hundred. The magazine is placed on the top of the gun, and with any great rapidity of firing has of course to be replenished very often: for which purpose two men at least are required, who are compelled to expose themselves above the gun, both the magazine and the men presenting a target to the enemy's fire.

The workmanship of all four of these guns is exquisite. Their weak point does not lie here, but arises from another cause which would be very difficult to remedy in them. It is said by some military men that no machine-gun has ever been brought into action which has not become "jammed" at the critical moment. Even if that be not strictly true, still the liability to accident from this cause is very great. A certain percentage of all cartridges fail to explode promptly at the instant of being struck: to use the technical expression, they "hang fire." Suppose that, while the handle of the gun is being worked at its highest speed, one of these sluggish cartridges happens to enter the barrel. It is struck; and instantly, before it explodes, the breech is opened, and the cartridge begins to be withdrawn again out of the barrel. At this instant the explosion takes place, breaks the shell in two, drives the front half forwards into the barrel, and blows the rear half out at the breech, and sometimes blows up the magazine. At any rate, it always drives the forward end of the cartridge firmly into the chamber of the barrel; and if the magazine does not explode, the next rotation of the crank drives a loaded cartridge into this chamber; the gun then becomes blocked or jammed, and is of no further use.

Maxim Automatic Gun.—It is many years since the writer conceived the idea of making a gun in which the *recoil* should be utilised for loading and firing; but it was not until 1883 that he had any time to devote to this problem. Before commencing experiments he considered carefully the different methods which might be employed for working an automatic gun by means of power derived

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from the burning powder. In those which he afterwards experimented upon, the power required was derived in the six following ways:—(1) power derived from the gases escaping from the muzzle of the gun, either by utilising their pressure directly, or by employing them as an ejector to produce a vacuum in a chamber near the muzzle of the gun; (2) power derived from the recoil of the entire gun; (3) power derived from the recoil of the barrel, the breech-block, and the lock; (4) power derived from a backward motion of the cartridge in the chamber at the instant of exploding; (5) power derived from only a portion of the cartridge moving backwards; (6) power derived from the elongation of the cartridge at the instant of exploding.

Experimental Apparatus.—The apparatus is now exhibited that was used for conducting experiments on a gun in which the power was derived according to the third of the above methods—namely from the recoil of the barrel, the breech-block, and the lock. As the writer was the first to make a gun of this kind, he had no data whatever to go upon, and had therefore to contrive some kind of device for ascertaining both the quantity and the character of the power to be dealt with. This apparatus consists of two parallel steel bars, clamped into supports, and having the barrel and the breech-block mounted between them. The whole is so constructed that all of the parts are adjustable. The distance through which the barrel recoils, before the breech-block becomes detached from it, is adjustable; the further distance that the barrel travels backwards, after the block becomes detached from it, is also adjustable; the travel given to the striker is adjustable; the angle at which the crank stands at the instant of explosion is adjustable; the amount of weight in the rotating parts and their distance from the centre of rotation are also adjustable.

This experimental apparatus was made as far as possible of soft steel and brass, in order that the action of the gunpowder might be observed upon the various parts. If any part showed signs of yielding under the strain, it was obvious that this part required strengthening in the gun ultimately to be made. The apparatus has already fired about a thousand cartridges, and at the present time is still in

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condition to be fired. With one hand on the muzzle the barrel can be pushed back with sufficient force to perform the whole cycle of operations for firing, the push of the hand taking the place of the recoil of the barrel. In this way it has been found that a pressure of about 60 lbs. travelling through a distance of seven-eighths of an inch is the power required for working the gun: which is very much less than the actual power derived from the recoil, as determined approximately by the writer in experiments with a Winchester rifle of the "express" pattern.

First Gun.—Having in this way determined the character and quantity of the power to be dealt with, and having ascertained the time required for the gas to escape from the barrel, as well as the strength required for the several parts, and the distance through which they had to travel, the writer proceeded to make his first gun, the construction of which is shown in the front and side elevations, Figs. 5 and 6, Plates 19 and 20, and in detail to a larger scale in Figs. 7 to 33, Plates 21 to 25.

The barrel A, Figs. 7 to 10, Plates 21 and 22, is encased throughout the greater portion of its length within a water-jacket, Fig. 10, which projects from the front end of the casing that encloses the machinery. Its backward motion, produced by the recoil of a shot just fired, is at first opposed by a pair of flat springs, one at each side, Fig. 8, which have to be forced apart by toggle struts TT recessed into the sides of the barrel, as shown in the plans, Figs. 12 to 14, Plate 23. As soon as these struts have passed the centre, the springs close together again, and thereby aid the further backward travel of the barrel. During the first half of the seven-eighths inch backward travel of the barrel, it carries the breech-block B with it at the same speed, the two being secured fast together by the locking catch C, Fig. 7, which is held firmly down under the crossbar D. But when the barrel has moved backwards through 7-16ths inch, the catch is free from under the crossbar, Fig. 9, and is lifted by a projection on its front end coming in contact with the face of the crossbar, thereby releasing the breech-block from the barrel. At the same instant a straight lever L centered

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upon the barrel, Fig. 8, encounters with one of its arms a stop S fixed in the casing, while its other arm bears against the toe of a sliding rod or striking bar R, the rear end of which bears against the breech-block B. Both the stop S and the toe of the bar R are made with long bearing faces slightly curved, as shown one-third full size in Figs. 12 to 14, Plate 23; and as the slightly curved arms of the transfer lever L roll over them, the respective leverages change very rapidly in relation to each other, and become inverted, with the result of imparting a rapidly accelerated motion to the breech-block. Consequently while the barrel A travels through the remaining 7-16ths inch of its backward motion, the breech-block B is driven backwards with sufficient force to carry the crank K over the back centre, Fig. 9; the radius of the crank is 3 inches, and the connecting-rod G from the breech-block is 6 inches long. The action of the transfer lever L in accelerating the breech-block has also the converse effect of simultaneously retarding the backward travel of the barrel; and all the backward motions cease at the instant of the crank passing the back centre, Fig. 9. With freshly loaded cartridges the momentum given to the crank and its attachments is found sufficient to drive the breech-block forwards again into its firing position and to fire the next shot. But with old and weaker cartridges the gun is found to work with greater certainty if a strong helical spring P is used, Fig. 8, to assist in drawing the breech-block forwards again into its firing position after the crank has passed the back centre. Consequently all guns made after the very first experimental gun are now provided with this spring.

Immediately upon the breech-block quitting the barrel, the tail of the extractor E, Fig. 9, Plate 22, and Figs. 32 and 33, Plate 25, which is a forked lever centered upon the barrel, comes against a stop fixed in its path; and the forked end of the lever, which takes hold of the cartridge rim or flange at each side, withdraws the empty cartridge shell about $\frac{1}{4}$ inch out of the barrel, Fig. 9. Its extraction is then completed by a hook I, Figs. 9 and 29, attached to the same crosshead as the breech-block. The hook runs underneath a pair of long fixed springs F, Figs. 7, 9, and 18, by which it is pressed

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down upon the cartridge so as to keep a secure hold while extracting it; but at each end the springs are curved slightly upwards, in order to reduce the pressure upon the hook in its foremost position, where it has to lift for catching hold of the cartridge flange, as well as in its hindmost position, where it has to be lifted again by the fixed incline J, Fig. 29, for releasing its hold of the cartridge. In this way the empty cartridge-case is drawn back, Fig. 30, into one of the grooves or pockets in the rim of the magazine or feeding cylinder M, Fig. 9, which is mounted upon an axis immediately beneath and parallel with the line of travel of the breech-block.

The magazine M, Figs. 18 to 20, Plate 24, is rotated intermittently by an arrangement of spiral ratchet-wheel and paul, shown developed flat in plan in Fig. 28, Plate 25, which is somewhat similar to the arrangement commonly employed in rock-drills for rotating the drill automatically between each blow: the motion of the breech-block in the last part of its backward travel, when the empty cartridge is entirely drawn out of the barrel, rotates the cylinder M through half the pitch or distance to the next groove or pocket, which has already been charged with a fresh cartridge; and the first part of the forward travel rotates it through the remaining half, bringing the fresh cartridge into the exact line of the barrel before the front end of the cartridge has reached the rear end of the barrel. The grooves or pockets in the magazine are charged one at a time in each back-stroke, from a belt of cartridges that passes over a flanged wheel W, Figs. 7, 9, and 17, Plates 21 to 24, which is situated in front of the magazine M, and is geared to it. The flanged wheel W has recesses in each flange for the ends of the cartridges to lie in. A hook or extractor H carried on the crosshead of the breech-block catches a cartridge in the backward travel of the breech-block, and draws it out of the belt into one of the pockets on the underside of the magazine M, where it remains while carried upwards step by step to the barrel by the intermittent rotation of the magazine. The empty belt passes out through an opening in the left-hand side of the gun casing, Figs. 17 and 20, Plate 24; and through an upper opening on the same side, Fig. 20, the empty cartridges drop out one by one from the pockets of the magazine as it rotates. During the

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backward travel of the breech-block a pivoted cover-plate N, Figs. 8, 18, 19, and 31, Plates 21 to 25, is thrown across laterally over the magazine by the pressure of a coiled spring, in order to prevent any risk of the cartridge being jerked upwards out of the magazine.

As the crank approaches the back centre, towards the end of the backward travel of the breech-block, the tail of the cocking lever O, Fig. 9, Plate 22, which is pivoted upon the crosshead, comes against a fixed stud; in the remainder of the backward travel the cocking lever then compresses the main spring, which is a helical spring coiled round the striking pin; and a suitable catch or sear Q, also hinged upon the crosshead, finally catches the nose of the cocking lever, and holds the striker cocked in readiness for firing the next shot.

The second half of the cycle of operations comprises those which are effected by the forward travel of the breech-block with its connections; and consists in pushing the fresh cartridge home into the barrel, locking the breech-piece, and releasing the sear Q for firing the shot. As soon as the crank has passed the back centre, it begins to push the breech-block forwards, with the fresh cartridge in front of it; and through the transfer lever L centered upon the barrel, Fig. 8, Plate 21, the quick travel of the breech-block B imparts a slow forward travel to the barrel A, sufficient to carry it forwards until the toggle struts TT pass the centre, and the flat side-springs are then in a position to urge it forwards to the end of its travel with the breech-block locked fast against it. In this final travel of 7-16ths inch under the action of the side springs, the sear Q coming into contact with a cam U, Fig. 7, releases the striker, which fires the cartridge. The cam is connected with an ordinary cataract or hydraulic buffer V, Fig. 7, of which the by-pass is throttled by an adjustable plug, Figs. 21 to 25, Plate 25; a hand-lever on the plug regulates the rate of firing so as to deliver any number of shots from two or three per minute up to as many as six hundred under favourable conditions. The handle on the cataract plug serves as a trigger for firing the gun by hand; for if the by-pass be opened while the gun is loaded, the explosion follows instantly; and

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if it be entirely closed, the gun though loaded cannot be fired at all.

The crank-shaft K is fitted with a handle Z outside the casing and opposite to the crank, Figs. 6 and 8, Plates 20 and 21, by which the gun is worked by hand at starting, until the first shot has been fired; the recoil then comes into action for continuing the firing automatically.

The gun is 4 feet 9 inches long over all, from the muzzle to the rear of the casing that contains the firing mechanism, Fig. 6, Plate 20. It stands about 3½ feet high upon its tripod. The belt supplying the cartridges is made of two lengths of canvas, Figs. 26 and 27, Plate 25, riveted together at regular intervals with brass eyelets and strips, so as to form a succession of loops, into each of which a cartridge is inserted by hand. When any belt is running out, a fresh one is hooked on to its tail end, without causing any delay to the continuous firing of the gun. By means of a simple appliance attached to the muzzle of the gun, Fig. 34, Plate 26 (see page 192), the smoke can be deflected in any direction desired, sideways or upwards, so as to give the gunner at all times a clear view of his aim. A gun of rifle calibre can also be made practically noiseless. The simple water-jacket encasing the barrel of the gun is found to answer very well for preventing excessive heating of the barrel, as the amount of heat required to evaporate water is so very great.

Working of Gun.—The gun is mounted here upon a tripod, Figs. 5 and 6, Plates 19 and 20, which is a very convenient stand for exhibiting its working. The tripod of course is not a necessary part of the gun, the mounting of which depends altogether upon whether it is wanted in the field or on shipboard. The crank handle Z projecting at the rear from the right-hand side of the gun is necessary in order to work the crank for bringing the first cartridge into the barrel of the gun; also for removing from the barrel any cartridge which may have failed to explode. The cartridges for supplying the gun are placed in a box B beneath,

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which may be made large enough to contain almost any number. In a light field-carriage about 2000 would be a fair supply; the box here shown holds 333, or one-sixth of that supply.

In turning the crank handle forwards and backwards, the feeding wheel and magazine are moved forwards one tooth at each turn: so that when the end of a belt of cartridges is introduced into the feed chamber, one cartridge is drawn in at each turn of the crank handle. Seven turns will draw seven cartridges out of the belt, and there will then be six cartridges in the magazine of the gun, and one in the barrel. On pulling the trigger, the cartridge in the barrel will explode, and its empty shell will be expelled from the breech of the barrel, which will instantly receive a fresh cartridge from the magazine; and the magazine in its turn will be supplied with another cartridge from the belt of cartridges.

When a cartridge enters the barrel, and the breech-block presses it firmly home, the block closes the breech of the barrel securely, the two being firmly locked together during the explosion of the cartridge, Fig. 7, Plate 21; and the breech cannot be opened again until the barrel, together with all its attachments which participate with it in the recoil, has moved backwards through 7-16ths of an inch, being half of its total travel of seven-eighths of an inch. By the time they have moved back through this distance, 7-16ths inch, the shot is already some distance out of the barrel, and the pressure of the gases is so far reduced that it is quite safe to open the breech. As the barrel recoils further, it becomes detached from the other moving parts; and while it is stopping, the breech-block with its attachments is sent rapidly backwards to a still greater distance. This further backward movement removes the empty shell from the barrel, and cocks the hammer; and then the return or forward travel of the breech-block pushes a fresh cartridge into the barrel, closes the breech, and pulls the trigger.

Seven cartridges having been drawn from the belt into the magazine of the gun, there are now six of them in the magazine, and one in the barrel. The regulating lever R of the trigger, Fig. 6, Plate 20, has been set forwards into such a position as will cause the gun to fire very slow. (Seven shots were here fired slow.) In

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this slow firing the whole of the various operations take place very rapidly, with the single exception of finally pulling the trigger for firing the shot. The speed of firing or rapidity of pulling the trigger is regulated by a piston working in the controlling cylinder or cataract, Fig. 24, Plate 25, which has an adjustable by-pass from one end to the other; the area of this passage way is regulated by a cock, and the cock is attached to the trigger lever. When the seven cartridges were fired very slowly, it was because the trigger lever R, Fig. 6, was pulled back only far enough to open the cock very slightly. If the lever be pulled further back, the speed of firing will be greater; while if it be pulled completely back against its stop, the whole seven cartridges will be fired in less than one second of time.

When the barrel with its attachments has recoiled through half its travel, and has thus reached the point at which the breech-block becomes detached from it, the remaining half of its travel has then to be occupied in bringing the barrel itself to rest, while at the same time withdrawing the breech-block rapidly from it through a much longer range of backward travel. This is accomplished by the single transfer-lever L, Plate 23, so contrived as to afford a great range of variation in its effective leverage. The breech-block B is thereby driven rapidly backwards at the expense of stopping the barrel A completely. Upon the return or forward movement of the block, the impact which would be expected from its closing against the end of the barrel is prevented by this same lever arrangement, whereby the barrel is caused to be already moving forwards in the same direction as the block before they come in contact, thus preventing any destructive hammering between them.

In Fig. 36, Plate 26, is shown, one-third full size, a diagram of the relative movements of the barrel and of the breech-block, set out upon a base-line KK which represents the length of the circular path described by the crank. The darker shaded area shows the short travel of the barrel; and the lighter area shows where the breech-block parts company with the barrel at one of the points P, and how it then continues its much longer travel while the barrel is stationary, and how it afterwards overtakes and rejoins the barrel

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at the other point P in the return or forward travel. Below the actual base-line KK is added also a dotted line DD, for indicating what would have been the virtual base-line, had the crank been arranged to make a complete revolution: instead of which it is a fundamental feature of this gun that the crank stops short on each side of its front centre, and rotates forwards and backwards alternately through somewhat less than a whole circle, as indicated in Figs. 6 and 7, Plates 20 and 21.

On introducing a belt of cartridges into the gun, and turning the crank handle, the cartridges are drawn in one by one, until the magazine is full, that is, until it is filled round half its circumference up to the barrel, and empty round the other half; and the empty part of the belt hangs out from the opposite side of the gun, Figs. 17 and 20, Plate 24. On pulling the trigger by hand, the first one of these cartridges is fired; and the gun will then supply itself from the belt and continue firing automatically as long as there are any cartridges in the belt. The firing can be stopped after only a single cartridge has been fired, or after two, three, or any other number up to a whole volley have been fired; and the gun can be made to fire either slow or with great rapidity. It is the first shot alone that requires to be fired by hand, after which the firing goes on automatically until stopped.

Hang Fire.—Suppose that any of the cartridges supplied to the gun should hang fire. At the instant of the cartridge being struck the breech is closed, and there is no power to open it automatically except the power locked up in the cartridge itself. This power does not develop itself until the cartridge itself explodes; consequently the breech does not open until after it has exploded, and the cartridge cannot be withdrawn in the act of exploding, as it can in other guns. Thus the serious trouble occurring with all other machine-guns in cases of hang fire cannot here occur, being rendered impossible by the very principle upon which the gun is constructed.

The case of a cartridge entering the barrel and failing to go off at all may be exemplified by placing in the magazine of the gun two good cartridges, then a bad one, and then two good ones. As

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soon as the first cartridge is in the barrel and has been fired by pulling the trigger by hand, the gun will fire the second cartridge automatically, and will attempt to fire the third or bad cartridge, but will fail. The bad cartridge has then to be removed from the barrel by working the crank handle by hand; the fourth cartridge has, like the first, to be fired by hand; after which the gun will fire the fifth automatically. The whole operation of passing the bad cartridge will occupy about half a second.

Hence, if a cartridge hangs fire, the gun waits for it; if it fails to go off at all, it must be removed by hand, which is done in about half a second.

Adjustment.—As the gun requires no external power for working it, being wholly self-contained, it may of course be turned freely in any direction while firing. For target practice, and for accurate shooting at long range, it is convenient to train it with screws, as in the case of other machine-guns; and suitable adjusting screws are accordingly provided, as shown in Figs. 5 and 6, Plates 19 and 20.

Suppose however that it be desired to give a quick adjustment as to elevation. For this purpose the clamping screw C is slackened on the telescopic elevating strut E, Fig. 6, Plate 20, and in a second the required elevation is approximately given; after which the clamping screw C is tightened up, and a final true adjustment is given in the ordinary manner by the fine regulating screw S. Again if it be desired to spread the fire horizontally between two given points, as across a bridge or a ford or a pass;—or to take accurate aim in the daytime upon a part of the enemy's position where he is expected to be at work at night;—in such cases the horizontal adjustment towards the right-hand side is made with one adjustable stop, and towards the left-hand side with another. The two stops can be set so as to give any spread that is wished, and to give it in any position desired. When so adjusted the gun can remain in this position till wanted, and can be fired in the night or at any other time with the certainty of covering everything between these two points without getting out of adjustment. For receiving cavalry or a sudden charge, the gun is clamped in elevation, but is left

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free to be moved completely round horizontally. For firing upon a quickly-moving torpedo boat, it is wholly unclamped so as to be moved freely in all directions.

The gun here shown is the size known as rifle calibre, which would doubtless be of great service in the field.

Naval Gun.—For naval purposes a very much larger gun is required, having sufficient power to destroy a torpedo boat completely at a single shot. For this purpose the writer is now making a gun large enough to take a cartridge with a shell of $1\frac{7}{8}$ inch diameter and 6 inches length, the shell or projectile having a percussion fuse and sufficient powder to give great penetration and a very long range, with a muzzle velocity of 2000 feet per second. This gun will be capable of being fired at the rate of about 150 shots per minute; but as the time that a torpedo boat will be in sight before she is near enough to destroy the ship is only from about ten to twenty seconds, it is not expected that the gun will ever have to be worked during a whole minute at its full speed. What is required is to fire a very large number of shots in a very short space of time. A six-pounder capable of piercing about 4 inches of steel plate could be fired about 50 times per minute.

Discussion.

Mr. Maxim showed the experimental apparatus described in the paper (p. 169), and the first gun made (p. 170); and also the last gun made, which had just been finished and mounted on its tripod stand in readiness to be shown at the Inventions Exhibition. He illustrated the description given in the paper by firing the first gun under the several conditions of slow and quick fire, and hang fire; and showed the handling and adjustment of the gun for meeting all the requirements arising in its use.

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Mr. CHARLES COCHRANE, having some time ago had the satisfaction of seeing the gun in operation at Mr. Maxim's factory, had been so pleased with it that he had felt sure it would form a very interesting subject for a paper for the Institution; and he was highly gratified that Mr. Maxim had listened to his appeal to bring the matter in this way before the members, all of whom he was satisfied must have been as much interested with the paper as he himself had been. The rapidity of firing—600 shots per minute—was he supposed beyond anything that had ever been heard of before. The only difficulty that occurred to him in such rapid firing from a single barrel was that of keeping the barrel cool, which he understood was accomplished by the application of the water-jacket. But if the gun were wanted in a country like the Soudan, he did not know where the water was to be got from for keeping the barrel cool. The application of the water-jacket he believed was not an absolute necessity in the conditions under which the gun would ordinarily be working, but it might be necessary if more powder were fired; and he should be glad if Mr. Maxim would be good enough to make this matter clear.

Mr. E. H. CARBUTT, M.P., as a mechanician, believed this automatic machine-gun to be one of the best mechanical inventions of the present century. Having had the pleasure of seeing the gun a good many times at the inventor's works, he thought that any one who had witnessed its working on the present occasion would agree with him that it was as near an approach to perfection in automatic action as any machine could be. The gunner had nothing to do but to give it the power of working, by firing the first shot by hand; and then, when the first cartridge had been fired, the gun would keep on firing perpetually until the belt of cartridges ceased to be fed to it. There was no doubt that in the modern state of warfare it would be a very useful auxiliary, particularly against a torpedo, which was only seen for such a short time that it was necessary to fire at it very rapidly. Moreover if the commander of an iron-clad wanted to look out at all, it was true that he had only a very small aperture through which to look out; but if an enemy

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having one of these guns were to traverse its fire across the aperture through which he was looking, he would be sure to be hit by the continuous stream of bullets discharged from the gun when firing so rapidly. So that in many ways the gun would come to be very useful.

In the Soudan, where the Gardner guns were in use, it had occurred that unfortunately at the very time when they were most wanted for service they jammed. That was a most disastrous thing, and in one case he believed it had very nearly resulted in a battle being lost; and it would certainly have done so, had it not been for the pluck of the men. That mishap arose from the fact that in the Gardner gun there was a mechanical feed, which must naturally go on at a certain speed; but in firing the cartridges they did not all explode at the same absolute speed; one cartridge might fail to explode so promptly as the rest, and as the machine still continued to go on, the slow cartridge either jammed itself in the barrel, or when it was thrown out on the ground it exploded there, and was thereby liable to do mischief to the men who were firing the gun. He had stated in the House of Commons, when the subject was under discussion, that he believed every machine-gun was liable to that accident. Mr. Nordenfelt, who was making a large number of his machine-guns at the present time, had written to him to say that his gun did not hang fire in that way, as others did, and that there was no risk of an unexploded cartridge being thrown out of the gun after having been placed in it to be fired. Having seen the Nordenfelt gun he thought that it could not very well hang fire, because if one barrel got jammed the other barrels could be worked without it. But in the Nordenfelt gun, instead of only a single barrel and a feeding chamber containing six or seven cartridges, there were four barrels as a rule, with a hopper feed; and the machine had to be fed by working a lever backwards and forwards. Although he had not seen the working of that gun in practice, and therefore could not speak except theoretically, it appeared to him that the mere action of moving the lever backwards and forwards must to a certain extent interfere with the sight, and he feared also to a certain extent with accuracy of aim. Of course that might be only a theoretical objection; but what he

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(Mr. E. H. Carbutt, M.P.)
considered the beauty of the Maxim gun was that there was here no mechanical action which would interfere in any way whatever with the firing, and therefore its fire could be aimed in any direction with the utmost accuracy and with the greatest facility. These were considerations that made this gun a very valuable one. Of course, until it had been tried in the rough and tumble of actual warfare and in the hands of soldiers who knew very little about it, there was not much likelihood of many faults being found in it; any faults that there might be would hardly turn up until after working the gun for some little time.

There was one point that had been mentioned to himself by Mr. Maxim, to which it might not be amiss to draw the attention of engineers interested in the manufacture of cartridges. A trial had lately been made in this gun of some beautiful cartridges of German make, which looked better than English cartridges; but the gun jammed in firing them. The reason was found out to be that the brass cartridge-case had not been properly fastened to the lead bullet; so that, when the cartridge had to be drawn out of the belt into the feeding wheel, the hook which took hold of the flange of the cartridge pulled the cartridge away from the bullet, and the bullet was left partly protruding beyond the proper length of the cartridge; so that, when it came to be carried round by the feeding wheel, of course it jammed. That was a thing that might happen to any gun with such cartridges. It would easily be overcome by running a groove round the neck of the brass cartridge-case, so as to fasten the lead bullet so securely that nothing of the kind could happen.

Already he believed Mr. Maxim was inventing improvements which would surpass even the best of the guns he had yet made; and no doubt eventually he would produce a gun which would be practically perfect and of the greatest service in the field. He could not help adding his testimony to the ability shown in the scheming of this machine-gun, which he hailed with the utmost satisfaction, because he was convinced that the more expensive war was made, and the more deadly the aim, and the larger the havoc that a gun of this kind could commit, the less likely were they to have war. Of course this gun would be an expensive one to fire. Six hundred cartridges

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per minute meant expending a large sum of money; but if by that means wars could be shortened, even by a single day, it would be worth any amount of money; and with a machine dealing such fearful destruction, the more likely would nations be to come to their senses and give up fighting, and settle their differences in other ways.

Mr. Bethell Burtan suggested, with regard to the supply of water to the jacket on the barrel of the gun, that in cases where water was scarce, as in the Soudan, oil would be very much superior for the purpose. If oil were applied, it would remain there and would not require to be replenished at all.

In regard to the difficulty of cartridges sticking in the gun in the manner mentioned by Mr. Carbutt, he recommended that the cartridge case itself should be made about half an inch longer, so as to encase the whole length of the bullet: instead of merely attaching it to the rear end of the bullet by crimping it in a groove, which had a bad effect not only upon the accuracy in shooting, but also upon the passage of the cartridge through the feeding mechanism of the gun, owing to the exposed paper patch getting rumpled up on the bullet, thereby causing an obstruction to the free entry of the bullet into the rifling of the barrel. Moreover the bullet when only stuck in the end of the cartridge was liable to be bent in transportation, thus creating another risk of the cartridge sticking in the barrel when entering the breech chamber.

Hang-fire occurred through defect in the fulminate of mercury contained in the cartridge. In the manufacture of the fulminate of mercury it had to be mixed with some other foreign matter; in the United States gunpowder was mixed with it, but in England he believed nitre was used. Either material had to be pulverised and mixed with the fulminate of mercury, and that operation was very dangerous. The mixture could not be so amalgamated but that in priming the caps a large portion of the foreign matter would sometimes get into the cap, carrying perhaps only a very small portion of the fulminate with it; and when it was struck, ignition and combustion were slow, owing to the foreign matter, and hang-fire was the consequence. All this difficulty could be overcome if

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(Mr. Bethell Burtan.)
in the manufacture of the fulminate it were first wetted, and then pulverised and mixed up thoroughly by a proper mixing process, so that there should be none of that unequal separation of the component matter.

Mr. C. T. DYKE ACLAND, M.P., expressing the very great pleasure and interest he had experienced in witnessing the wonderful invention now exhibited by Mr. Maxim, asked whether the gun had been tried at either of the arsenals or at Shoeburyness. From the explanations which had been given, he took it for granted that the inclination at which the gun was being fired made no difference whatever to the power of the recoil—whether the recoil was acting upwards or downwards. He also desired to ask whether the water in the jacket surrounding the barrel ever required to be changed; or would the same water last in the jacket without getting unfit to perform its function of keeping the barrel cool in firing? And had oil ever been tried instead of water? Also what was the weight of the gun?

Mr. WILLIAM B. BRYAN enquired what was the effect of the recoil upon the accuracy of aim at a long range. Though never having seen the gun before, he had heard of it, and had taken great interest in the descriptions he had received of it from officers of the Royal Artillery. Some information would be acceptable as to hang-fire and bad cartridges, because in some machine-guns those two points were absolutely of vital importance. From his own experience in rifle shooting he knew that hang-fire was a very awkward thing, even with a single-barrel rifle to the shoulder; and a bad cartridge was very much worse. With Martini-Henry rifles and with Snider rifles, when using a cartridge which had an iron base, he had seen the base sometimes come off; the extractor was then perfectly useless, and the rifle was rendered unserviceable unless a rod was put down the muzzle to extract the broken cartridge. By the use of solid-drawn cartridge-cases that difficulty was entirely prevented, because it was then impossible for the base to come off when laid hold of by the extractor. Moreover with the

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solid-drawn cases now made, the difficulty which had been spoken of in connection with the German cartridges, through the bullet getting loose from the case, could never occur with ordinary care in the manufacture.

Mr. J. A. Longridge had enjoyed an opportunity of seeing the gun previously at Mr. Maxim's works, where a considerable number of rounds had been fired very quickly indeed; and he thought it had a great future. No doubt practical use might show some difficulties which had not yet been anticipated; but he was sure the ingenuity so far displayed in the invention of the gun would enable the whole of them to be got over. To the heating of the gun he did not himself attach much importance; a moderate amount of water he thought would keep it sufficiently cool for all practical purposes. No doubt the gun would heat, and without the water-jacket the barrel might perhaps get so hot that the hand could not be held on it; but with the water casing he thought any practical difficulty of that sort was really not worth consideration. He hoped Mr. Maxim would succeed in getting his gun fairly tried; if he did, it would no doubt prove exceedingly successful, and would be of very great use indeed to any nation which was fortunate enough to take it up first.

Mr. Arthur Paget presumed there was no doubt that it was the evaporation of the water in the jacket encasing the barrel that kept the barrel cool; and this seemed to have been overlooked in the suggestion for the use of oil; and surely water was more easily to be obtained than oil, even in the desert. It would be interesting if Mr. Maxim would kindly state approximately the quantity of water that would be evaporated in half an hour's shooting at the greatest speed. They would then be enabled to realise what the difficulty was, if any. All must agree that the piece of mechanism here shown was exceedingly perfect and well thought out. He had seen something of previous machine-guns, which from their mechanical construction deserved a certain amount of admiration; but the piece of machinery to be admired most was that which was most

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(Mr. Arthur Paget.)

effectual and most simple. In this respect he thought there was no doubt that the Maxim gun bore a favourable comparison with any other in general use. As it was a simple piece of mechanism, the practical question might naturally arise, how many in case of immediate necessity could be turned out within a given period; and from that point of view he thought the Maxim gun would bear very favourable comparison with others. With a little organisation he believed that with a month's preparation these guns could be made at the rate of a thousand per month; that seemed a very large number, but he believed it was practicable, and that there were engineers present who could do it. He heartily thanked the author for his paper; and also Mr. Cochrane, Vice-President, for having been the means of getting so valuable a contribution to the proceedings of the present meeting.

The Hon. EDWARD MARJORIBANKS, M.P., wished to ask two questions. One was whether any experiments had been made with regard to the effect that would be produced on the accuracy of a rifle barrel by firing a stream of bullets through it at the rate of six hundred a minute; and how long a rifle barrel would last under such severe usage. In the second place he should like to know how a gun of rifle calibre could also be made practically noiseless. Information upon those two points would be interesting.

Mr. DANIEL ADAMSON desired to express his agreement with previous speakers as to the excellence of this gun. He should be glad to know how many small parts there were altogether, of which if one failed the firing would thereby be stopped; because in using the gun with great rapidity of firing, some parts would naturally be liable to fail and bring the gun to a stand-still, when of course its value as an instrument of warfare would be destroyed.

As to the suggested desirability of using oil to cool the barrel, instead of water, oil was the very worst material that could possibly be used under the circumstances. Since 1878, when he read a paper in Paris* on the mechanical and other properties of iron and mild steel,

* Journal of the Iron and Steel Institute, 1878, page 383.

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he had believed it had been admitted that all iron and steel suffered a loss of strength at a given temperature, and that the weakening they underwent was in proportion to the aggregate amount of the foreign ingredients they contained. It did not much matter whether the chief foreign ingredient was carbon or manganese or any other of the more noxious elements; it always brought upon the metal a weakness at a temperature of about 600° F. Now oil would not be vaporised until 612°; therefore it would allow the temperature to rise until the metal was in a most dangerous condition for sustaining anything like a percussive or explosive force. It was therefore quite inadmissible to use oil. If even only 2 per cent. of foreign material was associated with the iron, a most undesirable reduction of strength would be occasioned at a temperature somewhere about from 450° to 500°. If the percentage was still less, the temperature might be higher before brittleness set in; but in no case, even to the extent of only 0·2 per cent. (two-tenths of 1 per cent.) would iron so alloyed retain its strength up to the temperature of boiling oil. Oil was therefore utterly inadmissible for any such purpose. With perfectly pure iron that infirmity did not take place, although when heated to over 600° its strength would not be quite so great as at a lower temperature.

Mr. Maxim said, in regard to the use of water for keeping the barrel of the gun cool, the jacket surrounding it could be made if necessary to hold a gallon of water, or say about the weight of the barrel, namely 8 lbs.; then every 8 units of heat applied would heat that water through one degree of temperature. This would hold good until the temperature of the water had risen to 212°; at which point the latent heat of steam would come into play, with the result that heat sufficient to have melted five of the steel barrels would have to be applied before the temperature could be raised even a fraction of a degree, because water when free to evaporate at atmospheric pressure could not go above the temperature of 212°. Another thing to be considered was that, although in using good coal under a good boiler perhaps 10 lbs. of water might be evaporated with 1 lb. of coal, yet in that case the requisite supply of oxygen was obtained from the air without

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(Mr. Maxim.)
paying for it. But in gunpowder 75 per cent. of the weight of the powder was the material which carried the oxygen, and that was not all oxygen either; so that the actual amount of powder which could be used for heating purposes, and which was not used up as propelling power in the gun, was exceedingly small. Moreover the heating capacity of the barrel was not very great. Altogether therefore there was no trouble whatsoever in keeping the barrel cool with water; and it would take a very large amount of powder to evaporate a very small quantity of water, in the way in which the powder was used in the barrel. The water did not get unfit for use, and did not require to be changed; it remained in the jacket until evaporated by the heat of firing. Agreeably with what Mr. Adamson had said, he thought it would be found that iron did not deteriorate at all, and did not become any weaker, from being heated up to the boiling point of water; in fact he believed that low steel and iron increased in strength up to about 500°, when they rapidly fell off and became weaker. That was a temperature which of course the gun barrel could never reach.

The use of oil instead of water would not do at all. It would not dissipate the heat after the manner of water, as had been suggested; and its use in place of water could not therefore be contemplated.

With regard to the accuracy of aim in shooting, and the question whether the recoil interfered with it in any way, it was a fact that men who shot their rifle from the shoulder could make the very best possible target. He himself had taken an ordinary rifle, fastened it very securely, and fired ten shots into a fixed target, the gun never being moved during the loading; and he had afterwards fired the same gun from his shoulder, and had made just as good a target. Therefore a gun fired from the shoulder he considered would make as good a target as it was possible to make. In firing the gun from the shoulder it would be found that it always kicked through at least an inch and a half of space; the automatic machine-gun kicked through seven-eighths of an inch. The movement was co-axial with the barrel, and consequently there was no deviation, and the recoil did not at all interfere with the accuracy of fire.

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With regard to the German cartridges of which Mr. Carbutt had spoken, the firm that made them had never made any cartridges before; it was a new firm starting. Their cartridges were very handsome, the best cartridges he had ever seen in appearance; and he tried a few of them. It was soon found however that the cartridge-case and the bullet did not stick together, but pulled apart a little; consequently the cartridge was then rather too long to enter the feeding mechanism, and could not go through it without shearing the bullet off. He had sent them back, and the bullets had now been fixed in securely. Of the thousands of English government cartridges which he had fired in the gun, he had never known one single instance in which the primer had entirely failed; it always fired, even in the rare cases of hang-fire. He had never known one instance in which the bullet had come out of the cartridge-case before it was intended to do so; indeed he had never found a bullet loose enough to come out, or the head of the cartridge weak enough to pull off, in all the thousands of government cartridges he had used. The cartridges he had fired today were all government cartridges, solid-drawn, and he had never found one that failed. Solid-drawn cartridges were in fact the only cartridges which any machine-gun had ever used. Metallic cartridges were an American invention, and those made in the United States were made from Lake Superior copper and Lehigh spelter, both of which were exceedingly pure and of very great toughness. The cartridges made on the continent of Europe were not of sufficiently pure material; consequently they became very weak from the drawing process in making. The English government cartridges were quite porous at the base of the bullet, and the primers were not always fitted air-tight; and he thought hang-fire was due in a large measure to a very little moisture getting in there. After keeping cartridges in a damp place for some months, he had noticed that they would not fire quite so quickly as when they were fresh from the box. He had suggested that cartridges might be packed in their original box with some very powerful hygroscopic material, like phosphoric anhydride or calcium chloride. If the cartridges were really damp, he thought the addition of either of

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(Mr. Maxim.)
those chemicals, which had so powerful an affinity for water, would rob any ordinary damp cartridge of its moisture and make it dry in six months.

Mr. CHARLES COCHRANE asked whether the water for cooling the barrel had to be renewed, or whether the same water would last through a campaign.

Mr. MAXIM said that would largely depend upon the rate at which the shots were fired. The water was retained in the jacket by the stuffing-boxes, so that it could not get out as water; it could only get out as steam. On the top of the jacket there was a small plug at each end, held down by a little spring inside, which could be loosened by hand when firing, so as to allow any steam to blow out from the higher plug; there was a very simple automatic attachment for opening the higher plug and closing the lower, according to the inclination to which the barrel might happen to be tilted in firing. But he had never yet continued the firing so long as to see any steam blow out from either plug. Even on the supposition of continuing to fire at the rate of 600 shots per minute without intermission, he supposed it would be an exceedingly intricate matter to calculate how long the water would last, because it would be necessary to consider the amount of combustible really consumed in the barrel, the amount which developed itself as heat, the amount which developed itself as propelling force, and the amount of heat escaping at the muzzle of the barrel. All these were points which were not exactly known, but which would have to be taken into consideration. It would be found however that the amount of heat developed from the powder was so exceedingly small that, as far as the evaporation of water was concerned, he did not hesitate to say the quantity of water contained in the jacket round the barrel, which was less than two pints, would last for firing 30,000 shots continuously at the highest speed without being entirely evaporated; there would therefore he thought be no practical difficulty whatever in regard to water. It would also be remembered that the bore of the barrel was less than $\frac{1}{2}$ inch in diameter, while the outside diameter of the

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jacket was about 2½ inches; so that the outside cooling surface of the jacket exposed to the air was about five times greater than the inside heating surface of the barrel. Doubtless if the jacket were to be made a little larger, the water it contained would not evaporate at all.

With reference to the life-time of the gun, every part of the experimental apparatus now exhibited had been made exceedingly light, in order to test exactly the character of the recoil and how much it took to control it. The first gun made, of which the firing had here been shown, was in the main twice as strong, and in some parts four times as strong, as the original experimental apparatus; it had already been fired 14,000 times, and the barrel did not yet show any signs of wear. The last finished gun, also exhibited, was twice as strong as the first gun, and would certainly fire twice as long. Any one who had conducted experiments, especially in an untried field, with no data to go upon, would know something about how long it took to try experiments. The first work he had got done had been in France, for making the Winchester rifle load and fire itself. For conducting his experiments he had had to get suitable premises, and to furnish them with instruments and tools; and that had taken some time. In getting up the gun he had had to proceed very slowly, and had been experimenting upon it about eighteen months.

In regard to the shape of the gun, it would be observed that it had rather a long case. It fired at both ends of the stroke, and that made a very quick motion. Certain sacrifices of simplicity had been made for high speed. For larger cartridges, firing shells, of which it would not be wanted to fire a thousand, but only a few, the construction of the gun could be considerably simplified. In the newest form of gun that he had made, from which he had already fired 200 rounds, the entire length of the case that contained all the mechanism for loading and firing a projectile weighing rather more than 3 lbs. was only 22 inches; and he had found it was not necessary, in order for the gun to load and fire itself automatically, that it should be any more complicated than a gun loaded and fired by hand, provided the cartridge was made to drop in from the top, instead of having to be

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(Mr. Maxim.)

lifted and fed up from a store below. Large cartridges were not fired so fast that gravity could not be depended upon for feeding; consequently by having the cartridges fall into their proper place by their own weight, where it was not necessary to fire more than 120 shots a minute, the gun could be so far simplified as to be quite as simple as any machine-gun he had ever seen.

For getting rid of the smoke escaping from the muzzle of the gun in firing, he had devised an apparatus of which a sketch was shown in Fig. 34, Plate 26. By roughening like a rasp the surface of a plate of tin, and then painting it over, and fastening it at the muzzle of the gun alongside the path of the bullet, he had obtained from the smoke itself a clear delineation of the exact path that it took when it came out of the gun. At the instant when the bullet left the barrel, the gas was of course travelling at exactly the same speed, and was at a very high pressure. But its specific gravity at that high pressure was very low, on account of its very high temperature; consequently, instead of following the bullet as it might have been supposed to do, it instantly spread out laterally all round the muzzle M, Fig. 35, at right angles to the flight of the bullet B. He had accordingly mounted on the muzzle of the gun a cap or tubular chamber C, Fig. 34, having a diaphragm fixed across it, through which was a bullet-hole H of about $\frac{5}{8}$ inch diameter for a $\frac{1}{2}$-inch bullet. Though this hole was barely more than a bullet's length from the muzzle of the gun, yet scarcely more than 1 per cent. of the smoke passed out through it, the bulk of the smoke spreading laterally into the chamber, from which it escaped at once by the uptake U. By adding a second and third diaphragm beyond, with a similar bullet-hole through each, any little smoke escaping through the first hole H would be caught and drawn off by the draught of the uptake U, which would act like an ejector, producing a partial vacuum in the outer chambers; and the slender thread of smoke which always followed in the wake of a projectile with a flat base was all that would then issue from the mouth of the cap. If it were further desired to render the smoke invisible after it had thus been captured at the muzzle of the gun, an apparatus might be employed on the principle of Professor Tyndall's experiments for

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making dusty air quite pure by filtering it through a fibrous material saturated with glycerine. Of course an apparatus of that kind would require to be of some little bulk, but a very large amount of the noise as well as the smoke could thereby be got rid of. If there was a large gun-carriage with the back part made to carry a thousand cartridges, it could have such an apparatus in front of it. If the gun were wanted for an ambush, it would probably not matter if the additional part of the carriage were quite as extensive as the gun itself. From the cap on the muzzle of the gun the smoke-tube could be run back to the filtering apparatus in such a way that when the gun was fired there should be a suction of the smoke from the muzzle down through the fibrous material, and backwards and forwards until all the solid particles which rendered the smoke visible had been sifted out of it and collected in the box. If it were desired to get rid of noise still further, the working parts could be covered with felt, in which case very little noise would get through. Thus by somewhat increasing the bulk, the firing of the gun could be made practically noiseless, and also invisible as far as smoke was concerned.

The weight of the gun of the new pattern which he was now making would be about 30 lbs., exclusive of the tripod stand, which was not a necessary part of the gun.

In an inclined position of the gun for firing upwards or downwards, its action was unaffected by gravity, the force of the recoiling barrel being so great that the mere weight of the moving parts was altogether insignificant in the comparison.

Mr. Charles Cochrane asked if there was any danger of the firing being interfered with by the adjusting screws getting dirty in action.

Mr. Maxim believed all guns hitherto in use depended upon screws for their adjustment. Although of course screws could be got rid of altogether by mounting the gun on a universal joint free to move in any direction and clamped by friction, he did not think the adjusting screws of the gun exhibited could be effectually stopped

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(Mr. Maxim.)
by dirt. A sort of telescopic covering of soft leather might indeed be put over the adjustment, for preventing any dust from getting in, if the gun had to be employed in particularly dusty localities.

Mr. JOHN HAYES asked what amount of lubrication was necessary for the mechanism connected with the recoil, and whether those parts could be conveniently lubricated during the time the gun was in action.

Mr. MAXIM said that his first object had been to make a gun that would work at all as an automatic machine, irrespective of simplification; and he had been quite satisfied when the first shot fired the second. The next step was to put the gun into a presentable shape; and after having made a number of automatic guns that fired very perfectly, he had now proceeded to simplify the construction, so that the gun could be taken apart and put together quickly. In a later gun which he had made, capable of firing the larger government cartridges that would send a shot through one inch thickness of steel, the construction had indeed been so greatly simplified that he thought the only wonder would seem to be that it had not been invented before; it could be taken apart in forty seconds, and put together in forty seconds and fired. All the parts could be very easily duplicated.

As to the question whether oil was necessary for the lubrication of the working parts, that would depend largely upon the circumstances under which the gun was used. It had been found in the Soudan, he understood, that the Remington rifle which had its parts polished and free from oil answered best, because no dust adhered. But at sea, where there was salt air and no dust, it would be better to keep the parts oiled. For a very dusty country he should so adjust the parts as to have as few large surfaces sliding together as possible; and those parts should, as far as possible, be of hardened steel, or of case-hardened iron working upon very hard steel; the case-hardening he thought need not extend very deep. A steam-engine had to make many million turns in its life-time; not so a gun. It would be a very poor engine that would be worn completely out after a million

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revolutions. A gun, especially of the size now exhibited for firing the ordinary rifle-cartridges, would he thought give satisfaction if it should fire half that number; indeed the cost of the cartridges which the gun would fire before it was worn out would be formidable to contemplate.

Major George Mackinlay, R.A., asked how the gun compared in weight, expense, and number of parts, with other machine-guns.

Mr. Maxim replied that the gun which he should submit to the government, perfected as far as was at present possible, had quite as few parts, and as little weight, as any other single-barrel machine-gun, and would fire quite as fast as any four-barrel machine-gun. Moreover a machine-gun that would fire cartridges capable of piercing an inch thickness of steel required too much power to work it; a man was not strong enough to fire it rapidly. But this automatic machine-gun could be made as large as was desired, because the larger the gun and the larger the amount of power required to work it, the greater was the force of recoil available for doing the work. The new gun was as light and as simple as it was possible to make any other gun which could be worked with a single barrel and be loaded and fired by hand.

Mr. Edward Heneage, M.P., asked how soon the new gun was likely to be perfected. He should himself prefer to see some of these guns used in the army in their present state, instead of waiting a long time for a more perfect construction. The gun now exhibited was one of the most ingenious weapons he had ever seen; he had been perfectly astonished at its performance, especially at the facility with which all its movements went on at such marvellous rapidity. His only doubt had really been whether the adjusting screws might get clogged with grit; but it had already been explained how easily that could be prevented by the use of a soft leather case, which would not interfere with the action. He should like to press the question already asked as to how long it would take to turn out a certain number of the guns in the form now exhibited.

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Mr. MAXIM said he had at present only a small experimental establishment where he did not purpose doing anything except making samples or specimens—a single gun or perhaps half a dozen; it would be necessary for the manufacture to be carried on at some other place. The first gun made of the new pattern had already been fired two hundred times, and it worked exceedingly well. He could hardly say with what rapidity the gun could be produced in England; but other engineers present could no doubt answer the question. If every facility were given for making the guns, they could probably be turned out at about the speed suggested by Mr. Paget of a thousand a month.

The PRESIDENT observed that in the very interesting paper which had been read and discussed the principal points appeared to be these. The author had invented a machine-gun on a distinctly new principle, namely the self-acting principle; and he had carried out this idea in a way worthy of a man of science as well as of a sound mechanical engineer. It was not to be supposed that the result now brought before the meeting had been produced all at once. The gun exhibited was, as explained by the author, that which alone had survived out of a multitude of less successful attempts; and no doubt it was the fittest and the best. A great deal depended on the metallic cartridges. Until a high degree of perfection and uniformity had been attained with regard to them, it was quite clear that such a gun as this would not have been practicable; therefore its success was based in no small degree on the previous perfection of the cartridges. He quite agreed that it would be an enormous pity that this invention should not be secured for the benefit of this country. As to making the guns in quantities, it could readily be understood that the inventor's present establishment in London would be quite inadequate for producing on a large scale; but there were plenty of others throughout the country, the owners of which were anxious for work, and they would be able and willing to manufacture the guns in large quantities. He had just been told of one firm, who, if they had a month to make preparations, would be able to turn out a thousand a week; under

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these circumstances there would be no difficulty in obtaining a supply. History told of battles and even wars which had been lost or won by reason of some advantage in weapons upon one side or the other. It would be remembered that the battle of Sadowa, in which the needle-gun was first brought into operation by the Prussians, had been thereby decided in their favour. He was not at all sure that the possession of such an arm as the Maxim gun might not make all the difference between an easy short successful campaign and an arduous protracted unsuccessful one.

He had now the pleasure of asking the members to pass by acclamation a hearty vote of thanks to Mr. Maxim for his very interesting paper, and for the excellent illustrations he had given of the working of the gun.

In the course of the following day, Friday 1st May, the gun was inspected by the Right Hon. Earl of Northbrook, First Lord of the Admiralty; Sir Thomas Brassey, M.P., Secretary to the Admiralty; Mr. W. S. Caine, M.P., Junior Lord of the Admiralty; the Hon. H. R. Brand, M.P., Surveyor-General of Ordnance; Colonel the Right Hon. F. A. Stanley, M.P.; the Right Hon. W. H. Smith, M.P., late First Lord of the Admiralty; Sir Farrer Herschell, Q.C., M.P., Solicitor-General; Admiral the Right Hon. Sir John C. Dalrymple Hay, Bart., M.P.; Colonel Sir Walter B. Barttelot, Bart., M.P.; and the Hon. Edward Marjoribanks, M.P.; besides other distinguished visitors. At the conclusion of the adjourned meeting of the Institution in the evening, the gun was again described verbally by Mr. Maxim, and fired off to illustrate its action to the members and visitors present.

On Saturday morning, 2nd May, an inspection of the gun was made by the Premier, the Right Hon. W. E. Gladstone, who was received by the President, and Mr. Carbutt, M.P., Vice-President. The construction and working of the gun were described by Mr. Carbutt and Mr. Maxim. It was again fired off at different speeds, and the modes of training and handling to suit any of the conditions of actual warfare were fully explained.

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RESEARCH COMMITTEE ON RIVETED JOINTS.

REPORT UPON EXPERIMENTS ON DOUBLE-RIVETED LAP AND BUTT JOINTS, SERIES XI, XII, XIII.

By Professor ALEXANDER B. W. KENNEDY, *Honorary Life Member.*

The specimens tested in these three series were twelve joints, the special object of the experiments being the determination of the strengths of Double-Riveted Lap and Butt Joints. The joints were not arranged, as they had been in Series IX, to break in different ways, so as to determine the different resistances of the plate and rivets separately; but were designed to be the strongest possible joints of the given type and in the given thickness of plate, which should have equal strength in the plates and in the rivets, unless considerations as to bearing pressure prevented this equality from being reached. They were therefore girder joints rather than boiler joints, the latter kind requiring excess of plate area rather than equal resistance of plates and rivets.

The twelve joints as first tested formed Series XI, and were hand-riveted * to correspond with the former joints. After they had been all tested, four half joints (one from each of the four plates out

* The following description of the method of riveting the twelve joints in Series XI is furnished by Messrs. John Penn and Sons :—

The specimens were riveted up by one riveter using a hammer weighing 4 lbs., the rivet being held up with a dolly weighing about 26 lbs. The rivets were put in at a good red heat, and were not hammered after they had so far cooled as to lose all trace of redness in fair daylight. The rivet was first struck fair on the end to upset it, and then worked round the edge to form a rough head. The two parts of each specimen, while being riveted, were securely held in position on a slab, so as to keep them in line and avoid the necessity for any "setting" afterwards. The work of riveting was done by one of our ordinary hands, with ordinary care.

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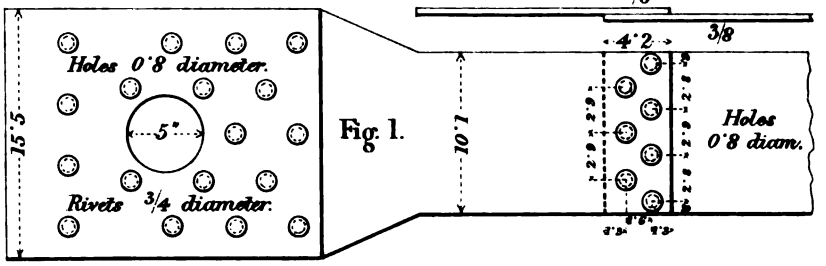
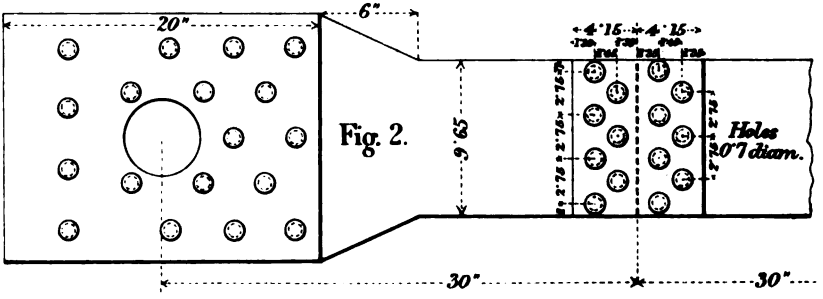
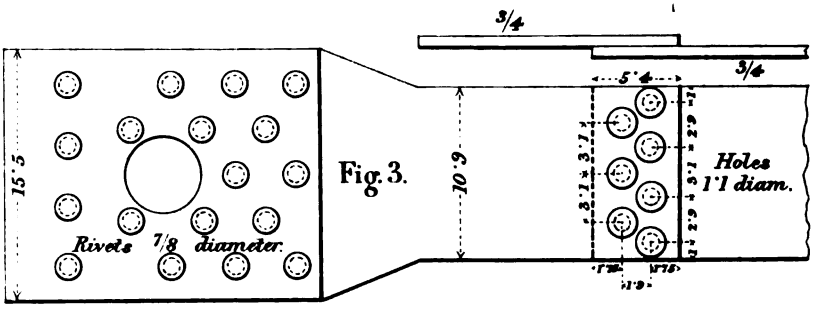
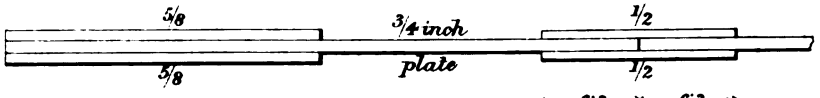
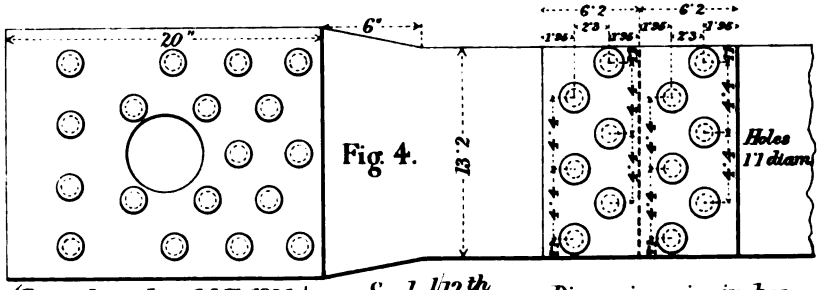
RIVETED JOINTS. Plate 27.











(Proceedings Inst. M.E. 1885.) Scale 1/12th Dimensions in inches.

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Diagrams of Slip of Joints.

Fig. 6.

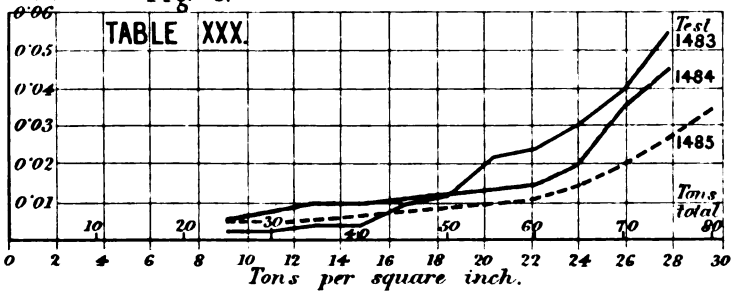

Fig. 5.

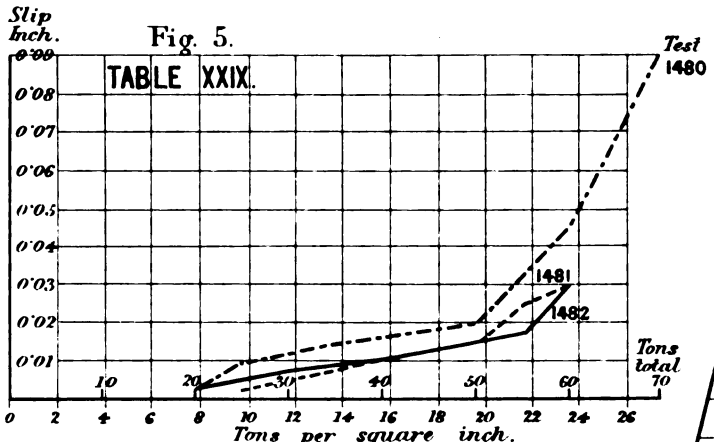

Fig. 7.

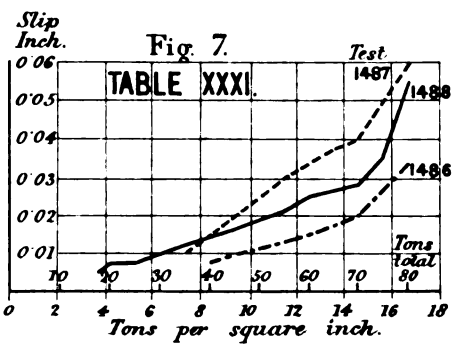

Fig. 8.

TABLE XXXII.

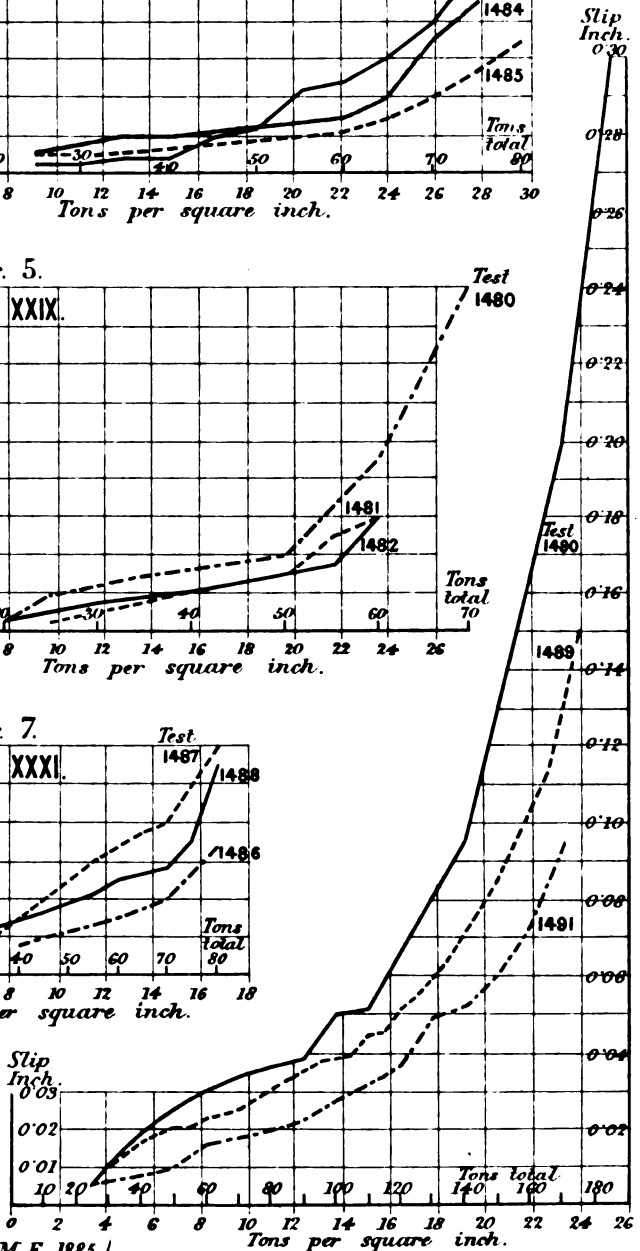

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Fig. 9.

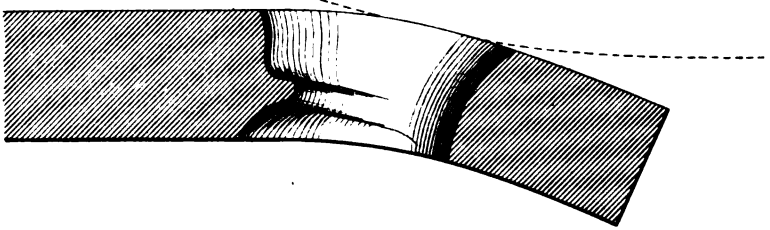


Fig. 10.

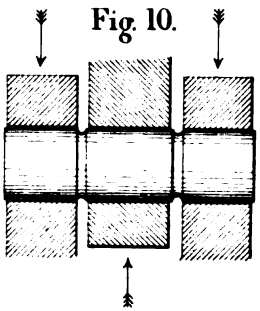


Fig. 11.

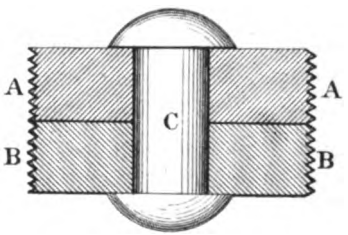
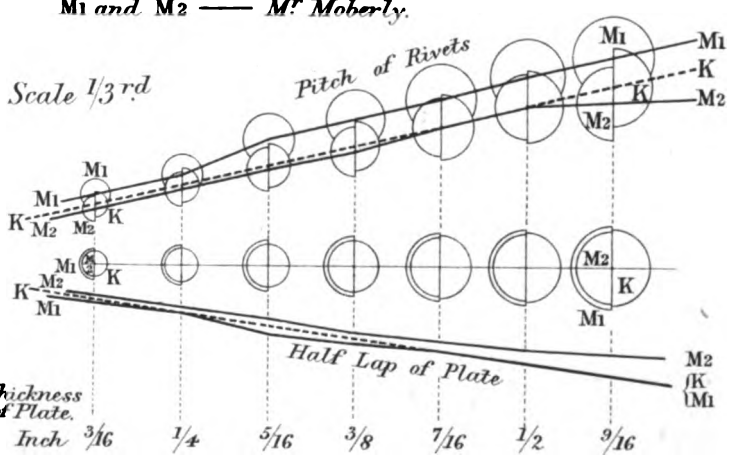


Fig. 12.

Diameter and Pitch of Rivets for Single-Riveted Lap Joints.

K *proportions by Professor Kennedy.*

M1 *and* M2 —— *Mr Moberly.*



(Proceedings Inst. M.E. 1885.)

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of which the whole series had been made) were cut up for tensile tests; and the remaining twenty half joints had their broken ends slotted off, and were re-drilled in the uninjured metal and formed into ten fresh specimens for Series XII. Series XII was thus precisely the same in form as Series XI, and was made from precisely the same plates. The joints in Series XII however were hydraulic-riveted, instead of being riveted by hand. This being absolutely the only difference between XI and XII, it was expected that the experiments would give some interesting information as to the value of hydraulic riveting. This expectation however was only partly realised, for reasons which will be stated further on. In order to obtain further information on this point, the broken joints of Series XII had their fractured ends once more slotted off, and were again drilled and riveted up in the uninjured metal. It was intended that these re-tests, which are numbered as Series XIII, should in part at least be riveted up at higher pressures than those used in Series XII. But by some accident this was not done: so that Series XIII is practically a duplication of Series XII.

It was not possible to work out directly from the results of the former experiments the best dimensions for these joints, for the four following reasons. (i.) The excess strength of the drilled over the unperforated plate could hardly (whatever theory be used to account for it) be so great with wide as with narrow pitches, and in Series XI the ratio of pitch to diameter was about $3\frac{1}{2}$ to 1, instead of about 2 to 1 as in former experiments with single-riveted joints. (ii.) The greater breadth of the double-riveted lap as compared with the single-riveted lap would give the joint greater stiffness, and by not putting so much tension on the rivets would probably increase their shearing resistance. (iii.) In the butt joints the rivet would be in double shear,—a point not as yet investigated by the Committee. (iv.) In all the double-riveted joints the question of the diagonal resistance of the plate, as affecting the diagonal pitch, comes in; and this question also involves constants not determined in any of the former experiments of the Committee.

Under these circumstances the writer had to use his judgment in modifying the constants already obtained for single-riveted joints, so

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as to make them suit the altered conditions. In doing this he made use not only of such of the experiments cited in Professor Unwin's Report as bore upon the point, but also of the later experiments made by Mr. Kirkaldy for the Board of Trade and published by Mr. Traill, and of the still more recent experiments made by Mr. Kirkaldy for Messrs. Easton and Anderson, the results of which were kindly placed at his disposal (before they were published) by Mr. Moberly. He also made use of the results of a number of small-scale experiments made by his own students on longitudinal or diagonal pitch in multiple riveting.

It was decided by the Committee to make experiments with both $\frac{3}{8}$-inch and $\frac{3}{4}$-inch plate, as being typical thicknesses for different classes of work. For each thickness, both double-riveted lap and double-riveted butt joints were tried; and of each size and type three exactly similar specimens were prepared and tested. There were thus twelve experiments in Series XI, besides the ten duplicate experiments in Series XII, and the same number in Series XIII.

The material for the joints, as in the former cases, was kindly supplied by the Landore Siemens-Steel Co. The drilling and riveting were done by Messrs. Fielding and Platt of Gloucester.

The hydraulic-riveting in Series XII and XIII was done on the machines of Mr. R. H. Tweddell, made by Messrs. Fielding and Platt. The writer believes that Mr. Tweddell made a number of observations in connection with the riveting processes, which were of considerable interest, and which he hopes will form the subject of a special report (see pp. 228–230).

The rivet holes were all drilled to gauges which have been measured by the writer: the rivets are assumed to fill the holes. The thickness of the plates, breadth of lap and of joint, &c., were measured by the writer personally before testing, and the exact actual dimensions were taken into account in calculating the areas given in the Tables appended (pp. 218–227). The nominal dimensions, which were very closely worked to by Messrs. Fielding and Platt, are given in Figs. 1 to 4, Plate 27; which also show the arrangement of the ends of the joints, stiffened up as formerly, and of the cover plates.

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The testing of Series XI was done at Lloyd's Cambria Chain Testing House, Saltney, near Chester, by Mr. A. S. Jack (the superintendent of the Testing House) and the writer. The testing of Series XII was done in the Chain Cable Testing House of the Mersey Dock and Harbour Board at Birkenhead, by Mr. W. Steel (the superintendent of the Testing House) and the writer. The Saltney machine is a dead-weight (lever) machine, so that it compares directly with the University College machine, on which the smaller tests were made. The Birkenhead machine can also be worked in the same way up to 100 tons; it is not so worked however, but is used simply as a hydraulic machine, the weights being used from time to time for verification. Above 100 tons the only verification is a small loaded check-ram. These checks were applied immediately after the experiments, and the small corrections found to be necessary were made, and are included in the results given in the Tables.

The experiments were carried out similarly to the former ones in all respects. Instead however of only noting the point at which visible slipping commenced, in Series XI the writer measured the amount of slipping of the joints as the loads gradually increased, with the results shown in the diagrams in Figs. 5 to 8, Plate 28, which will be afterwards discussed (page 211).

Double-Riveted Lap Joints, $\frac{3}{8}$-inch Steel Plate.

Fig. 1, *Plate* 27. Table XXIX, pp. 218–219.

The first three specimens of Series XI, Nos. 1480 to 1482, were double-riveted lap joints, of $\frac{3}{8}$-inch plate. The rivets were 0·8 inch diameter, 2·9 inches pitch transversely, and 2·15 inches pitch diagonally. This gives a ratio of plate to rivet area of 0·73 to 1·00; and it was assumed that, the unperforated plate having a tenacity of 30 tons, the joint would go when the stress in the plate was 31·5 tons per sq. inch, and in the rivets 23·2 tons per sq. inch. The area of the plate, measured diagonally (zigzag) between the rivets, was made 29 per cent. in excess of the net transverse area; and the margin was made equal to 1·1 times the rivet diameter (see report on Series X, 1882, p. 142). The joint was so proportioned

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that, at the stresses mentioned, the bearing pressure should be under 40 tons per sq. inch. The material for all three specimens was cut from the same piece of plate. In the result the first two joints broke by tearing the plate straight across; in the third the rivets sheared. It appeared therefore that the desired uniformity of strength had been very closely obtained. The average stress in the plate at the moment of fracture was 33·55 tons per sq. inch on the net area between the rivet holes, the average shearing resistance at the same time being 24·07 tons per sq. inch, and the average bearing pressure 40·86 tons per sq. inch. In No. 1480, considerably the weakest joint, the plate showed distinct lamination in the fracture; in 1481 very slight lamination. In 1482 all the rivets were sheared in the middle, one being also broken across just under the head.

In Series XII, 1480 was re-tested as 1480-1, and 1482 as 1482-1, each with precisely the same dimensions as before, but hydraulic-riveted. Both gave way by tearing the plates, the average load being almost precisely the same as the average of the same two joints in Series XI, the average stress in the plate being 32·93 tons per sq. inch. The difference between XI and XII here appears to be practically confined to the point at which slipping of the joint began, which will be considered later on (pages 211–212).

In Series XIII, which was a duplication of Series XII as already described, both these joints gave way by shearing the rivets, not by tearing through the plate. The shearing stress was only 21·57 tons per sq. inch when the rivets sheared, as against the 24 tons per sq. inch which the former rivets stood without shearing. The writer was not able to obtain any of this rivet steel to test separately afterwards; but as its shorn fracture was quite sound and silky, and as the rivets appeared to have filled their holes just as well as before, the natural inference is that this steel was of softer quality than that formerly used.* In the one joint (1482, Series XI) that previously gave way by shearing, the shearing stress was 24·8 tons per sq. inch —so great as to develop fully the strength of the plate; whereas here

* As to variations in shearing resistance of steel, see subsequent remarks p. 250, and Table XXXV, p. 262.

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the stress in the plate when the rivets gave way was only 29·57 tons per sq. inch, or much less than the stress at which the plate would itself have broken.

The plate from which the specimens of this set were cut had a tenacity (see Table XXXIII, pp. 226–227) of 29·97 tons per sq. inch. The excess strength in the plate due to perforation (taking only Series XI and XII for the reason just given) was therefore exactly 10 per cent., although the ratio of pitch to diameter was 3·62 to 1. The joint appeared to be of very closely uniform strength, the full shearing resistance (much higher than in single-riveted joints) being developed. It appears therefore that the load must have distributed itself very evenly over all the rivets, and that the strength of the joint could not be much increased by any change in its proportions.

As compared with the solid plate, the efficiency of the joint (mean of Series XI and XII) was 80 per cent. This high figure is of course due very much to the 10 per cent. of excess resistance just mentioned. It will be seen that none of the joints differed much from the mean. The low rivet-resistance of Series XIII brings its efficiency down to 67·1 per cent. It is obvious that a joint of maximum strength with this softer rivet-steel should have larger rivets and a larger pitch. This point will be considered in detail further on (pages 215–216).

DOUBLE-RIVETED BUTT JOINTS, ⅜-INCH STEEL PLATE.

Fig. 2, *Plate* 27. Table XXX, pp. 220–221.

Nos. 1483 to 1485 were double-riveted butt joints in ⅜-inch plate. The rivets were 0·7 inch diameter, and the pitch 2·75 inches transversely, or nearly 4 to 1. The diagonal pitch was 2 inches, the diagonal area being 27 per cent. more than the direct transverse area. The margin was equal to 1·43 times the rivet diameter. It was assumed that the joints would give way by the plate tearing at from 31 to 32 tons per sq. inch, the shearing stress (on the double area) being only about 15½ tons per sq. inch at the same time. In the result all the joints in Series XI went by tearing the plate straight across, the average stress at fracture being 30·36 tons per sq. inch, the shearing stress 15·08 tons per sq. inch, and the bearing pressure 42·28 tons per sq. inch.

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The machine-riveted joints of Series XII were a very little stronger, but practically of the same strength. The reduplicated joints of Series XIII however were distinctly weaker than the former ones. All nine joints broke across the plate fairly; but whereas the breaking stress in Series XI was 30·36 tons per sq. inch of net area, and in Series XII was 30·72 tons, in Series XIII it fell to 29·21 tons per sq. inch. On testing the tenacity of strips cut from the plate used for making these specimens (see Table XXXIII, pp. 226–227), it was found to be weaker than the former one, having a tenacity of only 28·24 tons per sq. inch. This accounts for the tenacity of the plate in the joint being less than before; but does not account for the difference between Series XII and Series XIII, which the writer finds himself unable to explain in any scientific fashion.

The excess strength of the plate (average of nine tests) is 6·6 per cent., which corresponds well enough with the increased proportionate pitch, the ratio of pitch to diameter being here 3·93 to 1. The welding of the plate showed itself to be very defective in No. 1484 (a most unusual occurrence in this class of material); and slightly defective in No. 1483.

The efficiency of the joint (mean of nine) was 79·8 per cent., or the same as that of the lap joints, the greater proportionate pitch more than making up for the loss of excess strength. It may be pointed out here that one of the specimens in Series XII was unavoidably made from a half of 1481 and a half of 1485, as corresponding halves were not available; and the same thing had to be done again in 1487–1489, the only alternative being to waste the odd pieces instead of utilising them.

By still further reducing the diameter of the rivets, keeping the pitch the same, it is possible that the strength of the joint might be increased. The consequent increase in the bearing pressure however (see report on Series X, 1882, p. 142) made the writer think that he had gone as far as was safe in this direction; and it is probable that the proportions chosen are very closely those of maximum strength with the materials experimented upon. The plate area is only 0·494 (or say one half) of the rivet area.

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The joint therefore is already unsuited for boiler work: so that in a boiler it would probably not be possible to get a joint of the double-riveted butt type in $\frac{3}{8}$-inch steel plate, which should have an efficiency of 80 per cent., although this can be readily done in a girder.

It should be noticed that, while seven out of the nine joints broke straight across the line containing four rivet-holes, two actually took the line of the three holes, and therefore broke diagonally at the ends, as shown in the sketches at the foot of Table XXX, p. 220. It appears therefore that the 27 per cent. of additional zigzag area which this joint has is only just sufficient to make the diagonal spaces equally strong with the others. The same remark applies also to the former set, where the excess of zigzag area was 29 per cent. (see sketches at foot of Table XXIX, p. 219).

DOUBLE-RIVETED LAP JOINTS, $\frac{3}{4}$-INCH STEEL PLATE.

Fig. 3, *Plate* 27. Table XXXI, pp. 222–223.

The $\frac{3}{4}$-inch double-riveted lap joints of Series XI were numbered 1486 to 1488. The rivets were here 1·1 inch diameter, pitched 3·1 inches apart transversely and 2·45 inches diagonally, the excess of area in the latter direction, measured zigzag, being 35 per cent. The margin was 1·1 times the rivet diameter. In order to prevent the outside rivets from being too close to the edges, while keeping the whole breadth of the joint $3\frac{1}{2}$ pitches, as before, they were brought in 0·2 inch nearer to the centre than corresponded with the full pitching. The same thing was done in Nos. 1480–1482 to a smaller extent, as will be seen from Fig. 1, Plate 27. The joints were calculated to break when the tensile stress was 31·5 tons per sq. inch, and the shearing stress 23 tons per sq. inch. The bearing pressure in this case was quite low.

In this case all the joints in which the plate tore went straight across, which may fairly be attributed to the somewhat greater excess of zigzag area, namely 35 per cent. instead of 27 per cent. The three joints of Series XI all gave in the plate, the average stress being 31·21 tons per sq. inch. Of the three joints of Series XII one gave by shearing the rivets at 21·57 tons per sq. inch, a little less than before.

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The other two gave by tearing through the plate at a mean stress of 30·15 tons per sq. inch, also somewhat lower than before. The five joints which thus broke through the plate gave a mean resistance of 30·69 tons per sq. inch of net area. This shows an excess over the unperforated plate of 7·8 per cent. This is a smaller excess than would be expected in a thinner plate, the ratio of pitch to diameter being only 2·82 to 1.

In Series XIII all three joints gave way by shearing the rivets. The lower stress at which this occurred may probably be due to the use of a different quality of rivet steel from that formerly employed. There is no doubt however that the final resistance of the rivets must have been diminished by the pull put on them by the bending of the very soft plate. A section after fracture was actually as shown in the sketch, Fig. 9, Plate 29, a ridge of metal being fairly squeezed inwards as the head was pulled in by tension coming on the rivet.

The appearance of the plate in the fracture is by no means all that could be desired, and perhaps its irregular structure may have helped to diminish its excess strength. As it is however, it has gone at almost exactly the load at which it was calculated to break. As four of the nine joints went by shearing, it is satisfactory to know that the proportions of uniform strength have again been reached, and this time with dimensions suitable for boiler work. It is certainly remarkable that, for whatever reason, the joints which were riveted up by hydraulic pressure were the ones which ultimately gave way through the rivets.

The actual ratio of plate to rivet area in the joints is 0·71 to 1·00, which gives another confirmation of the original results that the shearing resistance of steel rivets does not exceed that of iron rivets in nearly the same ratio that the tenacity of steel plates exceeds that of iron plates. So that here, as before, it is necessary to make the plate area much less than the rivet area in order to get a joint of uniform—and therefore of maximum—strength.

The mean efficiency of the five joints which broke through the plate is 70·2 per cent.; of the four which broke by shearing the rivets 61·8 per cent. The mean of all nine is 66·5 per cent.; and, allowing

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for practical inequalities of material, this appears to be about the greatest efficiency which can be obtained with a double-riveted lap joint in $\frac{3}{4}$-inch plate. The only way of increasing the efficiency would be by using larger rivets; and it is not probable that this will be done, at least at present. The reason for which the efficiency of this joint is so much less than that of a $\frac{3}{8}$-inch one is of course simply that it is impossible to use rivets so large in proportion to the thickness of the plate, and impossible therefore to use so large a pitch in proportion to the diameter of the rivets.

The fact that the proportions best (if we could only use them) for a $\frac{3}{8}$-inch and a $\frac{3}{4}$-inch joint of the same type are practically the same speaks volumes for the extremely uniform character of the material used; for it is well known what differences may be expected to be found between $\frac{3}{8}$-inch and $\frac{3}{4}$-inch plates of iron.

Double-Riveted Butt Joints, $\frac{3}{4}$-inch Steel Plate.

Fig. 4, *Plate* 27. Table XXXII, pp. 224–225.

The last three specimens, Nos. 1489–1491, were $\frac{3}{4}$-inch double-riveted butt joints. They were made with the same size rivets as the last, 1·1 inch diameter, with a pitch of 4·4 inches; and to avoid the possibility of going to too high a total load (the Saltney machines working only to 250 tons), they were limited to 3 pitches in breadth, instead of $3\frac{1}{2}$, and the rivets were therefore unavoidably unsymmetrical. The diagonal pitch was 3·18 inches, which gives an excess area of 26 per cent. The margin was 1·27 times the rivet diameter. The thickness of metal outside the rivet nearest to the edge was half a diameter, as it had been before: so that it was not thought necessary to make the joint still more unsymmetrical by narrowing the outer pitch in the way already described. The ratio of plate to rivet area, the rivets being in double shear, was 0·63 to 1·00. It was assumed that the joint would break by tearing the plate at 30 tons per sq. inch, which was taken as the strength of the unperforated plate, it being improbable that there would be any excess resistance with so large a pitch. The corresponding shearing stress would be under 19 tons per sq. inch; but as the bearing pressure would be 45 tons per sq. inch at the same time, it

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was not thought possible to use smaller rivets. The plate however tore at a much lower load than was anticipated, namely at an average in Series XI of only 26·47 tons per sq. inch, when the shearing stress was 16·81 tons and the bearing pressure 39·49 tons per sq. inch.

The two pieces of the set twice re-tested in Series XII and XIII (1490–1 and 1491–1, and 1490–2 and 1491–2) went at the still lower stress of 25·10 tons per sq. inch, or about 5 per cent. less than before. In no case was the fracture very satisfactory, either in this case or in the other $\frac{3}{4}$-inch plate. The tensile specimens cut from the same plates however are quite usual in their appearance. The writer is inclined to think that the large amount of crystal in the fracture may be due to the uneven tearing, which visibly started in each case at one of the very thin bridges, outside the outer rivet-holes. The form of the specimen in this respect could not be altered, unless the number of rivets was largely increased; and probably the broad joints of actual practice would give better results than their particular test-representatives.

Taking the mean of the seven specimens, we have a tensile stress at fracture of 25·7 tons per sq. inch, which, as the plate itself gave 27·83 tons per sq. inch in tension, shows a *loss* of nearly 8 per cent., with a pitch of four diameters. A gain of strength was not to be expected; but the writer cannot account for the loss, unless upon the grounds mentioned above. In spite of this however, the large pitch has brought the mean efficiency of the joint in the seven tests up to 69·2 per cent., the efficiency of the three hand-riveted joints being 71·3 per cent. If, as the writer believes, so large a pitch as four times the rivet diameter is not admissible in a boiler, it will not be possible in boiler work to get so high an efficiency with $\frac{3}{4}$-inch steel plates and rivets in a double-riveted butt joint.

Joint No. 1489 was the only one of this set which broke straight across the joint; all the others broke straight across to the last rivet of the row, and then ended by tearing diagonally into the next row and out through the edge rivet-hole of that row. It would not appear unreasonable at first sight that the comparatively low results here obtained might be due, wholly or partly, to the partly diagonal

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fracture. This appears to be disproved however by the result, as 1489 is the weakest, not the strongest, of these three first joints. In this connection it is right that the mode of fracture of 1490 &c. (diagonal at one end) should be distinguished from the case when fracture takes place diagonally (zigzag) right across the joint. In the case under consideration the joint slowly tore across from the one edge, and the maximum load had been borne on the straight area long before the fracture began to run diagonally, by which time there was comparatively little stress in the joint, what there was being all localised towards one side. The narrow bridge however was cracked generally before this occurred, and this may have contributed to the early fracture of the joint.

Tenacity of Steel Used.

In Table XXXIII, pp. 226–227, are given the results of tensile tests of twelve pieces cut (three from each) from the four plates used in making the joints of Series XI, XII, and XIII. These pieces were cut out of the body or unstrained part of the specimens after fracture in Series XI; and for this purpose one half each of Nos. 1481, 1485, 1487, and 1489 was used up. The remaining halves of these four joints were paired together, as already mentioned, and made into two of the joints of Series XII and Series XIII. The modulus of elasticity of some of the tension pieces was measured, and agrees very well with the measurements formerly made in Series I, &c.

The writer did not make any special tests of the rivet steel, which was supposed to be of the same quality as that formerly used; but from other experiments recently made on similar material in double shear, with specimens of the form shown in the sketch, Fig. 10, Plate 29, it appears that in the $\frac{3}{8}$-inch lap joints the full resistance of the steel was developed, and very nearly as much in the $\frac{3}{4}$-inch lap joints. In both cases the resistance is really more than could have been expected, considering the great tension put on the rivets by the bending of the plates. It has been already remarked, p. 202, that in Series XIII a somewhat softer and weaker quality of steel appears to have been used.

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INFLUENCE OF MODE OF RIVETING.

In conclusion there remain to be considered the differences between the joints in Series XI and in Series XII and XIII, —differences due to the mode of riveting.

The *ultimate strength* of the joint is not shown to have been much affected by the different modes of riveting. Practically the double-riveted lap joints in $\frac{3}{8}$-inch plate, Table XXIX, pp. 218–219, were equally strong in Series XI and XII. In Series XIII these joints broke by shearing the (softer) rivets.

The double-riveted butt joints in $\frac{3}{8}$-inch plate, Table XXX, pp. 220–221, were also practically the same in Series XI and XII. In Series XIII however these joints showed a falling off of about 5 per cent. in strength, although they still broke through the plate. This discrepancy, as already stated, p. 204, the writer is not able to account for.

The double-riveted lap joints in $\frac{3}{4}$-inch plate, Table XXXI, pp. 222–223, do not show much difference in strength between Series XI and Series XII. The machine-riveting gives a joint about $2\frac{1}{2}$ per cent. less strong in the cases where the plate tore. This may very probably be connected with the fact that the pressure on the rivets was not sufficient for so large a size. As already mentioned, p. 199, the joints of Series XIII were to have been riveted up with a heavier pressure, but by some misunderstanding this was not done. In Series XIII a somewhat softer rivet-steel was used, p. 202; and as the joint was so proportioned that a slight alteration of the material would determine in what way it would break, this difference made the joints give way by shearing the rivets at a somewhat lower load than in the cases where the plate was torn.

The double-riveted butt joints in $\frac{3}{4}$-inch plate, Table XXXII, pp. 224–225, were distinctly weaker in the hydraulic-riveted Series XII than in the hand-riveted Series XI by about 5·4 per cent. The re-tested joints of Series XIII were very slightly stronger than in Series XII, but were still more than 5 per cent. weaker than in Series XI, as in the similar joints in $\frac{3}{8}$-inch plate. The plate from which the joints were made was a defective one, as has been pointed out, p. 208, but was no worse for the later than for the earlier experiments.

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If the defective strength in Series XII had been due to the initial load put on in breaking Series XI (which the writer does not believe to be possible, although it has been suggested), we should have expected to find a still further diminution of strength in Series XIII, instead of which there is a slight increase.

Although however the ultimate strength of the joints has been not much affected by the mode of riveting, and on the whole the hydraulic riveting has appeared the weaker, the case is quite altered when we look at the load at which slip commences, instead of the maximum load. For many purposes this lower load is the more important, as representing something like the load under which the joint would leak in a boiler. The diagrams, Figs. 5 to 8, Plate 28, show the results of measurements of slip made during test on the joints of the hand-riveted Series XI. The measurements were made between scribed lines on the edges of the joints, the distances being read on a steel scale with the aid of a strong magnifying glass. As was formerly noticed in every case, quite visible slip—visible without any glass—occurred always at a very low load indeed. The loads at which it occurred in Series XI are given in the following Table :—

No. of Experiment. *Figs.* 5 to 8, *Pl.* 28.	Type of Joint. Double-Riveted. *Figs.* 1 to 4, *Plate* 27.		Average Load at which visible Slip began.	Percentage of Breaking Load.
Series XI.		*Figs.*	Tons.	Per cent.
1480,81,82	Lap, $\frac{3}{8}$-inch plate	1, 5	21·7	25·2
1483,84,85	Butt, „ „	2, 6	25·0	30·4
1486,87,88	Lap, $\frac{3}{4}$-inch „	3, 7	31·7	21·2
1489,90,91	Butt, „ „	4, 8	25·0	12·9

Having once begun, the slip does not remain stationary for a time, and then slowly increase, as if it were really slip caused by the joints coming into bearing on the rivets; but it increases steadily until the limit of elasticity of the material is reached, and then goes on more rapidly. It was impossible to say at what point in the operation leakage would begin; but it may reasonably be taken as proportional to the load at which slipping commenced. The most

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noteworthy point in the Table just given is that the load at which slip begins in the different joints is ludicrously out of proportion to their strength, being practically the same for the $\frac{3}{8}$-inch and the $\frac{3}{4}$-inch joints. The difficulty is not removed by comparing the bearing pressures at which slip occurs; they are about 11 tons per sq. inch in the $\frac{3}{8}$-inch joints, and 5·5 tons per sq. inch in the $\frac{3}{4}$-inch joints. Such very visible motion can hardly be due to either crushing or stretching of the steel, which would be too small to be so easily visible: so that it would appear that its cause must be partly "give" in the rivet-holes, and partly the commencement of bending of the plate, either of which might readily cause visible slip.

With the joints riveted in Mr. Tweddell's machines very different results were obtained, as is shown in the following Table:—

Type of Joint. Double-Riveted.	Average Load at which visible Slip began.		Percentage of Breaking Load.		
Figs. 1 *to* 4, *Plate* 27.	Series XII.	Series XIII.	Series XII.	Series XIII.	Mean.
	Tons.	Tons.	Per cent.	Per cent.	Per cent.
Lap, $\frac{3}{8}$-inch plate...	47·5	35·0	55·4	45·4	50·4
Butt, „ „ ...	53·7	54·0	64·9	68·7	66·8
Lap, $\frac{3}{4}$-inch „ ...	49·7	46·7	31·2	33·3	33·7
Butt, „ „ ...	56·0	69·0	30·6	37·5	34·0

Here the same very remarkable peculiarity occurs, that the load at which slipping began is practically very little more in the $\frac{3}{4}$-inch than in the $\frac{3}{8}$-inch joint; but with the vital difference that the absolute value of this load is *more than double what it was before.* In the hand-riveted joints in $\frac{3}{8}$-inch plate slipping began at 27·8 per cent. of the breaking loads, while here it begins at 58·6 per cent. of the breaking loads. In the hand-riveted joints in $\frac{3}{4}$-inch plate slipping began at 17 per cent. of the breaking loads, in the hydraulic-riveted at 33·8 per cent.

It has long appeared to the writer impossible that in joints which distorted so much as these before fracture the hydraulic riveting should have any influence on the breaking load, compared with good

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hand-riveting; but he has maintained that its value lay in increasing the initial stiffness of the joint, a matter of at least equal and probably of greater importance. This view seems to be very fully confirmed by the results of the present experiments.

It may be added that, as all the observations for slip were made by the writer himself personally and in the same manner and with the same magnifying glass, he believes that the figures given are as strictly comparable as the nature of the case allowed.

Efficiencies of Joints.

In reference to the calculated efficiencies of the joints a word of explanation may be necessary. On commencing these tests of double-riveted joints the writer adopted the particular arrangement of rivets shown in Figs. 1 to 4, Plate 27, with the view of securing symmetry of arrangement in reference to the pull, and therefore the greatest possible uniformity of stress. Each joint therefore (except the $\frac{3}{4}$-inch butt joints) had two rows of rivets in it, one of four and one of three rivets, and had thus a breadth equal to $3\frac{1}{2}$ pitches. In order to obtain symmetry a considerable sacrifice was thus made. For while such a joint would have $3\frac{1}{2}$ times the rivet area of a joint 1 pitch wide, and therefore could be compared with that standard if it broke through the rivets, yet its plate area is somewhat less than $3\frac{1}{2}$ times that in a single pitch, because the plate was bound to break through the section in which were four rivet-holes, whereas proportionately to its total breadth there should have only been $3\frac{1}{2}$ holes. The difference is not very great, but is too great to be neglected. In those joints therefore in which the total breadth was $3\frac{1}{2}$ pitches and which broke across the plate, the efficiency given is not that of the actual joint broken, but is the efficiency which a joint of 4 (or any whole number of) pitches in breadth would have if it broke with the same stress per square inch and in the same manner as the actual joint. In future experiments the balance of practical advantages will probably lie on the side of making test-joints an even number of pitches in breadth, and rather putting up with possibly unsymmetrical pull than having to make this calculated correction in the efficiencies.

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HIGHER RIVETING PRESSURES.

The writer regrets that the question of the influence of higher riveting pressures on the larger rivets has not been tested. If a few additional experiments could be made for this purpose, he believes they would add considerably to our knowledge, and at the same time would form a needed completion to the long series of experiments which the Committee has now carried out.

FORMULAE AND PROPORTIONS DEDUCED FROM EXPERIMENTS.

The writer has received and read with much interest the letter from Mr. W. Silver Hall, a member of the Riveting Committee, which is appended to this Report, pp. 231-235. He has suggested to Mr. Hall that before publication it should be modified in one or two particulars of minor importance. Only as to the question raised by Mr. Hall, respecting a formula for proportioning double-riveted joints, he thinks it right to say something. The original formulæ given by the writer (Proceedings 1881, p. 229), based upon the results of the best experiments up to Series VIII, gave for single-riveted lap joints

$$1{\cdot}47\,(p-d)\,t = \tfrac{\pi}{4}\,d^2 \qquad (1)$$

$$\text{and } 0{\cdot}82\,(p-d)\,t = t\,d \qquad (2)$$

The first equation connects the plate and rivet areas; the second connects the plate area with what may be called the pressure area, i.e. the product of the diameter d of the rivet hole into the thickness t of the plate. It assumed that the joint would break by tearing the plate when the stress in the plate reached about 32·5 tons per sq. inch of net area; or by shearing the rivets when the stress in them reached about 22 tons per sq. inch; or in one or other fashion when the bearing pressure exceeded 40 tons per sq. inch. The working out of equation (2) gave the (rounded off) results—

p = pitch = $2\frac{1}{4}$ times diameter of hole,

d = diameter of hole = $2\frac{1}{4}$ times thickness of plate.

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These proportions, as Mr. Hall shows, have been justified very fully for similar joints by the excellent experiments of Mr. Moberly.

But when the writer began to work out the proportions of the double-riveted joints, it was necessary of course to change these formulæ, for the reasons already given in this report. In working these out for the double-riveted lap joints, it was preferable to work from equation (1) than from equation (2). The shearing resistance of the rivets is more certainly known than the resistance of the plate to pressure, even after the experiments of Series X (1882, pp. 138–143), which threw considerable light on this point. Then also a double-riveted lap joint will never give way in consequence of an excess bearing pressure; for with no ordinary proportion of rivet to plate area can that pressure be made detrimentally great before the joint breaks either by tearing or shearing. Equation (1) does not work out so conveniently as (2), but gives

$$p = 0{\cdot}53\,\frac{d^2}{t} + d$$

from which the pitch p can be found at once, only if *both* the diameter d and the thickness t be given. This however is not very inconvenient practically, for with double-riveted joints it seems advisable to make the rivets as large as possible in proportion to the thickness of the plate; and the size of rivet having been thus fixed, the formula gives at once and easily the proper pitch. This formula was the one employed by the writer in proportioning the various lap joints of Series XI to XIII. The following short Table (page 216) gives the value of the constant (0·53 above) in the formula, corresponding with the average results of experiments in Series XI to XIII, and worked out for various tenacities of plate and various shearing resistances of rivets.

It will be seen that practically there is no difference between the values of the constant for $\frac{3}{8}$-inch and for $\frac{3}{4}$-inch plate; and also that practically the proportions for 30-ton plate and 24-ton rivets are suitable likewise for 28-ton plate and 22-ton rivets.

We may therefore say that, in order to design a double-riveted lap joint of maximum strength in steel plate of any thickness from

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TABLE OF PROPORTIONS OF DOUBLE-RIVETED LAP JOINTS,

IN WHICH $p = a\frac{d^2}{t} + d$

Thickness of Plate.	Original Tenacity of Plate. Tons per sq. inch.	Shearing Resistance of Rivets. Tons per sq. inch.	Value of Constant a.
$\frac{3}{8}$-inch	30	24	1·15
„	28	24	1·22
„	30	22	1·05
„	28	22	1·12
$\frac{3}{4}$-inch	30	24	1·17
„	28	24	1·25
„	30	22	1·07
„	28	22	1·14

$\frac{3}{8}$-inch to $\frac{3}{4}$-inch, we may assume the rivet-diameter as large as we find it possibly practicable to make it, and then fix the pitch thus:—

For 30-ton plate and 24-ton rivets } $p = 1{\cdot}16\frac{d^2}{t} + d$

„ 28 „ 22 „

„ 30 „ 22 „ $p = 1{\cdot}06\frac{d^2}{t} + d$

„ 28 „ 24 „ $p = 1{\cdot}24\frac{d^2}{t} + d$

The only limit here to the size of the rivets, besides convenience of work, is the bearing pressure; and practically no rivets that will be used with joints such as we are considering will give us an excessively high bearing pressure. For instance, suppose even 1-inch rivets to be used with $\frac{3}{8}$-inch plate, the pitch would be 4·1 inches, and the bearing pressure, when there was 30 tons per sq. inch stress in the plates, would be 46·5 tons per sq. inch, which although large is only just over the limit that we know can be safely allowed.

For a double-riveted butt joint the conditions are different. Here it is impossible to develop the full shearing resistance of the joint without getting excessive bearing pressure, because we have doubled the shearing area without increasing the area on which the pressure acts. In the double-riveted butt joints in $\frac{3}{8}$-inch plates, for instance, the working out of the formula just given makes $p = 2{\cdot}36\frac{d^2}{t} + d$.

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For $d = 0{\cdot}7$ inch (as in the joints tested) this would give $p = 3{\cdot}78$ inches, and the pressure on the rivets would be 70 tons per sq. inch before the proper breaking stress of the plate was reached. Doubtless such a joint would break at too low a load, probably by shearing the rivets at 16 to 18 tons per sq. inch (see Series X, 1882, p. 143). Here therefore we must use the formula (2) in page 214, equating the tearing resistance of the plates to the bearing resistance of the rivets. Taking the plate tension as 30 tons per sq. inch, and assuming that we may allow as much as 45 tons per sq. inch bearing pressure, this becomes for the $\frac{3}{8}$-inch plate

$$0{\cdot}35\,(p-d)\,t = t\,d$$

and for the $\frac{3}{4}$-inch plate

$$0{\cdot}33\,(p-d)\,t = t\,d$$

or practically the same in each case. Working out this gives

For 30-ton plates $p = 3{\cdot}9\,d$

„ 28 „ „ $p = 4{\cdot}2\,d$

the bearing pressure being assumed at 45 tons per sq. inch in each case.

Approximately therefore the pitch should be four times the diameter, rather less in proportion as the tenacity of the steel increases. In the thicker plates it is possible to increase the pitch somewhat more in proportion than in the thinner ones; for the equation $p = 2{\cdot}5\,\frac{d^2}{t} + d$, which would correspond with 30-ton plate and 24-ton rivets, gives for $\frac{3}{4}$-inch plate and $1{\cdot}1$ inch rivets a bearing pressure of 50 tons per sq. inch. This, although too great, is still notably short of the 70 tons per sq. inch which would accompany a similar method of proportioning in $\frac{3}{8}$-inch plate.

As regards the diagonal pitching of the rivets, it seems certain that the net diagonal area, or area of plate along zigzag line of fracture, should not be *less* than 30 per cent. in excess of the net area straight across the joint; and 35 per cent. is better than 30 per cent.

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TABLE XXIX. (*see continuation on opposite page*)

SERIES XI *Hand riveted.* SERIES XII AND XIII *Hydraulic riveted.*

Seven Rivets in each joint. *Holes drilled* 0·8 *inch diameter.*

Series.	Test number.	*Fig.* 1, *Plate* 27. Dimensions. Thickness. Inch.	Breadth. Inches.	*Fig.* 5, *Plate* 28. Visible Slip began. Tons.	Total Breaking Load. Tons.	Tearing Area. Sq. Ins.	Tensile Stress per sq. in. Tons.
Series XI. *Hand riveted.*	1480	0·379	10·10	20·0	82·47	2·604	31·67
	1481	0·361	10·11	25·0	86·96	2·485	34·99
	1482	0·379	10·10	20·0	88·59	2·604	34·00
			Means	**21·7**	**86·01**		**33·55**
Series XII. *Hydraulic riveted.*	1480–1	0·379	10·10	45·0	84·50	2·604	32·45
	1482–1	0·379	10·10	50·0	87·00	2·604	33·41
			Means	**47·5**	**85·75**		**32·93**
Series XIII. *Hydraulic riveted.*	1480–2	0·379	10·10	35·0	76·25	2·604	29·28
	1482–2	0·379	10·10	35·0	77·75	2·604	29·87
			Means	**35·0**	**77·00**		**29·57**

(*see continuation on opposite page*)

Nature of Fracture.

Test No. 1480. Plate tore straight across. Fracture silky, distinctly laminated.
„ 1481. Do. do. Do. very slightly laminated.
„ 1482. Rivets sheared. Fracture silky.

Test No. 1480–2. Rivets sheared. Fracture silky.
„ 1482–2. Do. Do.

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(*continued from opposite page*) **TABLE XXIX.**

Double-Riveted Lap-Joints in $\frac{3}{8}$-inch Steel Plate.

$\frac{\text{Pitch}}{\text{Diameter}} = \frac{2 \cdot 9}{0 \cdot 8} = 3 \cdot 62$. *Tenacity of Plate* 29·97 *tons per sq. inch.*

(*continued from opposite page*)

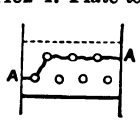
Shearing Area. Sq. Ins.	Shearing Stress per sq. in. Tons.	Bearing Area. Sq. Ins.	Bearing Pressure per sq. in. Tons.	Breaking Load per inch breadth of $\frac{3}{8}$ in. plate. Tons.	Efficiency of Joint. Per cent.	Nature of Fracture. *See Foot-notes.*
3·57	23·10	2·14	38·54	8·58	76·3	Plate tore.
3·57	24·30	2·04	42·63	9·46	84·2	Do.
3·57	24·80	2·14	41·40	9·20	81·8	Rivets sheared.
	24·07		**40·86**	**9·08**	**80·8**	
3·57	23·67	2·14	39·49	8·78	78·1	Plate tore.
3·57	24·37	2·14	40·65	9·03	80·3	Do.
	24·02		**40·07**	**8·90**	**79·2**	
3·57	21·36	2·14	35·63	7·47	66·5	Rivets sheared.
3·57	21·78	2·14	36·33	7·62	67·8	Do.
	21·57		**35·98**	**7·54**	**67·1***	

* This lower efficiency is no doubt attributable to the use of softer steel for the rivets in Series XIII. See Report, page 202.

Nature of Fracture.

Test No. 1480–1. Plate tore at AA. Fracture silky, distinctly laminated.

„ 1482–1. Plate tore at BB Do. do.



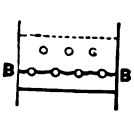


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TABLE XXX. (*see continuation on opposite page*)

SERIES XI *Hand riveted.* SERIES XII AND XIII *Hydraulic riveted.*

Seven Rivets in each side of each joint. Holes drilled 0·7 *inch diameter.*

Series.	Test number.	*Fig.* 2, *Plate* 27. Dimensions. Thickness. Inch.	Breadth. Inches.	*Fig.* 6, *Plate* 28. Visible Slip began. Tons.	Total Breaking Load. Tons.	Tearing Area. Sq. Ins.	Tensile Stress per sq. in. Tons.
Series XI. *Hand riveted.*	1483	0·403	9·67	25·0	84·02	2·766	30·38
	1484	0·383	9·66	25·0	80·84	2·627	30·77
	1485	0·399	9·65	25·0	81·62	2·727	29·93
			Means	**25·0**	**82·16**		**30·36**
Series XII. *Hydraulic riveted.*	1483–1	0·403	9·67	49·0	85·00	2·766	30·73
	1484–1	0·383	9·66	45·0	80·50	2·627	30·64
	1481–1 / 1485–1	0·391	9·65	67·0	82·50	2·678	30·80
			Means	**53·7**	**82·70**		**30·72**
Series XIII. *Hydraulic riveted.*	1483–2	0·403	9·67	55·0	81·00	2·766	29·28
	1484–2	0·383	9·66	48·0	77·00	2·627	29·31
	1481–2 / 1485–2	0·391	9·65	59·0	77·75	2·678	29·03
			Means	**54·0**	**78·58**		**29·21**

(*see continuation on opposite page*)

Nature of Fracture.

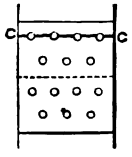
Test No. 1483. Plate tore at CC. Fracture silky, granular, somewhat laminated.

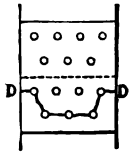
„ 1484. Plate tore at CC. Fracture silky, much laminated.

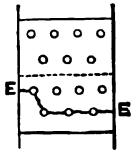
„ 1485. Do. Do. do.

„ 1483-1. Plate tore at DD. Fracture silky, considerably laminated.

„ 1484-1. Plate tore at EE. Fracture silky, much laminated.







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(*continued from opposite page*) **TABLE XXX.**

Double-Riveted Butt-Joints in $\frac{3}{8}$-inch Steel Plate.

$\frac{Pitch}{Diameter} = \frac{2{\cdot}75}{0{\cdot}70} = 3{\cdot}93.$ *Tenacity of Plate* 28·24 *tons per sq. inch.*

(*continued from opposite page*)

Shearing Area. Sq. Ins.	Shearing Stress per sq. in. Tons.	Bearing Area. Sq. Ins.	Bearing Pressure per sq. in. Tons.	Breaking Load per inch breadth of $\frac{3}{8}$ in. plate. Tons.	Efficiency of Joint. Per cent.	Nature of Fracture. *See Foot-notes.*
5·45	15·42	1·99	42·32	8·50	80·3	Plate tore.
5·45	14·83	1·88	43·00	8·62	81·4	Do.
5·45	14·98	1·99	41·52	8·36	78·9	Do.
	15·08		**42·28**	**8·49**	**80·2**	
5·45	15·60	1·99	42·72	8·60	81·1	Plate tore.
5·45	14·77	1·88	42·82	8·58	81·0	Do.
5·45	15·14	1·99	41·45	8·62	81·6	Do.
	15·17		**42·33**	**8·60**	**81·2**	
5·45	14·86	1·99	40·70	8·19	77·3	Plate tore.
5·45	14·13	1·88	40·96	8·20	77·5	Do.
5·45	14·27	1·99	39·07	8·13	76·8	Do.
	14·42		**40·24**	**8·17**	**77·2**	

Nature of Fracture.

Test No. 1481–1. } Plate tore at CC. Fracture silky, laminated. The plate
1485–1. } which tore through was the one belonging to Test 1481; but the strength of the weaker plate is taken into account in the efficiency. If the strength of the stronger plate were considered, the efficiency would be 76·8 per cent., and the mean efficiency 79·6 per cent.; and there would be a similar alteration in the corresponding test in Series XIII.

" 1483–2. Plate tore at CC. Fracture silky, laminated.

" 1484–2. Plate tore at CC. Fracture silky, laminated in places, and welding a little defective.

" { 1481–2. } Plate tore at CC. Fracture silky, much laminated. See the
{ 1485–2. } above note to the corresponding test in Series XII.

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TABLE XXXI. (*see continuation on opposite page*)

SERIES XI *Hand riveted.* SERIES XII AND XIII *Hydraulic riveted.*
Seven Rivets in each joint. Holes drilled 1·1 *inch diameter.*

Series.	Test number.	*Fig.* 3, *Plate* 27. Dimensions. Thickness. Inch.	Breadth. Inches.	*Fig.* 7, *Plate* 28. Visible Slip began. Tons.	Total Breaking Load. Tons.	Tearing Area. Sq. Ins.	Tensile Stress per sq. in. Tons.
Series XI. *Hand riveted.*	1486	0·736	10·93	40·0	148·2	4·796	30·90
	1487	0·726	10·95	35·0	150·0	4·738	31·66
	1488	0·736	10·95	20·0	149·4	4·807	31·08
			Means	**31·7**	**149·2**		**31·21**
Series XII. *Hydraulic* riveted.*	1486–1	0·736	10·93	61·0	148·0	4·796	30·86
	1487–1	0·746	10·93	38·0	143·5	4·872	29·45
	1489–1						
	1488–1	0·736	10·95	50·0	145·0	4·807	30·16
			Means	**49·7**	**145·5**		**30·16**
Series XIII. *Hydraulic* riveted.*	1486–2	0·736	10·93	51·0	139·1	4·796	29·00
	1487–2	0·746	10·93	54·0	142·5	4·872	29·25
	1489–2						
	1488–2	0·736	10·95	35·0	139·0	4·807	28·92
			Means	**46·7**	**140·2**		**29·06**

(*see continuation on opposite page*)

* These joints were riveted up with too low a hydraulic pressure. See Report, page 210.

Nature of Fracture.

Test No. 1486. Plate tore straight across. Fracture 40 per cent. crystalline; the rest silky; laminated.

„ 1487. Plate tore straight across. Fracture silky, somewhat porous, fine laminations of crystal.

„ 1488. Plate tore straight across. Fracture 20 per cent. finely crystalline, much laminated, and irregular in structure.

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(*continued from opposite page*) **TABLE XXXI.**

Double-Riveted Lap-Joints in $\frac{3}{4}$-inch Steel Plate.

$\frac{Pitch}{Diameter} = \frac{3 \cdot 1}{1 \cdot 1} = 2 \cdot 82$. *Tenacity of Plate* 28·46 *tons per sq. inch.*

(*continued from opposite page*)

Shearing Area. Sq. Ins.	Shearing Stress per sq. in. Tons.	Bearing Area. Sq. Ins.	Bearing Pressure per sq. in. Tons.	Breaking Load per inch breadth of $\frac{3}{4}$ in. plate. Tons.	Efficiency of Joint. Per cent.	Nature of Fracture. *See Foot-notes.*
6·723	22·04	5·70	26·00	14·96	70·0	Plate tore.
6·723	22·31	5·62	26·69	15·34	71·9	Do.
6·723	22·22	5·70	26·22	15·07	70·6	Do.
	22·19		**26·30**	**15·12**	**70·8**	
6·723	22·01	5·70	25·97	14·96	70·0	Plate tore.
6·723	21·34	5·74	25·00	14·31	68·3	Do.
6·723	21·57	5·70	25·44	13·50	63·2	Rivets sheared.
	21·64		**25·47**	**14·26**	**67·2***	
6·723	20·69	5·70	24·40	12·97	60·7	Rivets sheared.
6·723	21·19	5·74	24·83	13·10	62·8	Do.
6·723	20·67	5·70	24·38	12·95	60·6	Do.
	20·85		**24·53**	**13·01**	**61·4†**	

† This lower efficiency is no doubt attributable to the use of softer steel for the rivets in Series XIII. See Report, pages 202 and 206.

Nature of Fracture.

Test No. 1486-1. Plate tore straight across. Fracture 75 per cent. crystalline; the rest silky and laminated.

" 1487-1. 1489-1. Plate tore straight across. Fracture 50 per cent. crystalline; the rest silky. Broke in the half corresponding with 1489, the tenacity of which, 27·83 tons per sq. inch, has been taken in the efficiency.

" 1488-1. Rivets sheared. One rivet slightly defective. All seven rivets sheared.

" 1486-2, 1487-2 1489-2, 1488-2. Rivets sheared. Fracture silky.

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TABLE XXXII. (*see continuation on opposite page*)

SERIES XI *Hand riveted.* SERIES XII AND XIII *Hydraulic riveted.*
Six Rivets in each side of each joint. Holes drilled 1·1 *inch diameter.*

Series.	Test number.	*Fig.* 4, *Plate* 27. Dimensions. Thickness. Inch.	Breadth. Inches.	*Fig.* 8, *Plate* 28. Visible Slip began. Tons.	Total Breaking Load. Tons.	Tearing Area. Sq. Ins.	Tensile Stress per sq. in. Tons.
Series XI. *Hand riveted.*	1489	0·740	13·20	25·0	192·2	7·312	26·28
	1490	0·737	13·20	25·0	194·3	7·290	26·65
	1491	0·739	13·24	25·0	194·2	7·332	26·48
			Means	**25·0**	**193·6**		**26·47**
Series XII. * *Hydraulic riveted.*	1490–1	0·737	13·20	50·0	182·5	7·290	25·03
	1491–1	0·739	13·24	62·0	184·0	7·330	25·10
			Means	**56·0**	**183·1**		**25·07**
Series XIII. * *Hydraulic riveted.*	1490–2	0·737	13·20	78·0	186·0	7·290	25·51
	1491–2	0·739	13·24	60·0	181·5	7·330	24·76
			Means	**69·0**	**183·7**		**25·13**

(*see continuation on opposite page*)

* These joints were riveted up with too low a hydraulic pressure. See Report, page 210.

Nature of Fracture.

Test No. 1489. { Plate tore straight across. } Fracture 65 per cent. crystalline; the rest silky.

" 1490. } Plate tore partly diagonal. { " 30 " do. do.
" 1491. } { " 50 " do. do.

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(*continued from opposite page*) **TABLE XXXII.**

Double-Riveted Butt-Joints in $\frac{3}{4}$-inch Steel Plate.

$\frac{Pitch}{Diameter} = \frac{4 \cdot 4}{1 \cdot 1} = 4 \cdot 0$. *Tenacity of Plate* 27·83 *tons per sq. inch.*

(*continued from opposite page*)

Shearing Area. Sq. Ins.	Shearing Stress per sq. in. Tons.	Bearing Area. Sq. Ins.	Bearing Pressure per sq. in. Tons.	Breaking Load per inch breadth of $\frac{3}{4}$ in. plate. Tons.	Efficiency of Joint. Per cent.	Nature of Fracture. *See Foot-notes.*
11·52	16·69	4·91	39·14	14·75	70·7	Plate tore.
11·52	16·87	4·89	39·73	14·98	71·8	Do.
11·52	16·86	4·90	39·60	14·89	71·3	Do.
	16·81		**39·49**	**14·87**	**71·3**	
11·52	15·84	4·89	37·32	14·06	67·4	Plate tore.
11·52	15·97	4·90	37·55	14·10	67·6	Do.
	15·90		**37·43**	**14·08**	* **67·5**	
11·52	16·15	4·89	38·05	14·33	68·7	Plate tore.
11·52	15·75	4·90	37·04	13·91	66·7	Do.
	15·95		**37·54**	**14·12**	* **67·7**	

Nature of Fracture.

Test No. 1490–1. } Plate tore partly diagonal. { Fracture 50 per cent. crystalline; the rest silky, granular.

„ 1491–1. } { „ 65 per cent. crystalline; the rest silky.

„ 1490–2. Do. „ almost entirely crystalline.

„ 1491–2. Do. „ about 75 per cent. crystalline.

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TABLE XXXIII. (*see continuation on opposite page*)

SERIES XI, XII, XIII. *Elasticity and*

Numbers of specimens cut from same plate.	Test number.	Dimensions of Strips of 10 inches length.			Limit of Elasticity per square inch.		Breaking Load per square inch.	
		Breadth. Inch.	Thickness. Inch.	Area. Sq. Inch.	Lbs.	Tons.	Lbs.	Tons.
1482, 1481, 1480.	1481–1	1·498	0·370	0·554	46,280	20·66	66,560	29·72
	1481–2	1·497	0·367	0·549	46,480	20·75	66,660	29·76
	1481–3	1·493	0·352	0·525	55,000	24·55	68,180	30·44
				Means	**49,250**	**21·99**	**67,130**	**29·97**
1485, 1484, 1483.	1485–1	1·493	0·402	0·600	52,600	23·48	63,000	28·12
	1485–2	1·494	0·396	0·591	43,990	19·64	63,620	28·40
	1485–3	1·492	0·391	0·583	46,650	20·83	63,200	28·21
				Means	**47,750**	**21·32**	**63,270**	**28·24**
1488, 1487, 1486.	1487–1	1·500	0·736	1·104	45,380	20·26	64,640	28·86
	1487–2	1·500	0·732	1·098	45,320	20·23	62,660	27·97
	1487–3	1·500	0·720	1·080	47,770	21·32	63,930	28·54
				Means	**46,160**	**20·60**	**63,740**	**28·46**
1491, 1490, 1489.	1489–1	1·500	0·728	1·092	48,720	21·75	61,920	27·65
	1489–2	1·500	0·725	1·087	49,280	22·00	62,380	27·85
	1489–3	1·500	0·716	1·074	45,440	20·28	62,730	28·00
				Means	**47,810**	**21·34**	**62,340**	**27·83**

(*see continuation on opposite page*)

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(*continued from opposite page*) TABLE XXXIII.

Tenacity of $\frac{3}{8}$-inch and $\frac{3}{4}$-inch Steel Plates used.

(*continued from opposite page*)

Ratio of Limit to Break.	Extension in whole length of 10 inches. Per cent.	Reduction of Area at fracture. 'Per cent.	Specific Extension; and Modulus of Elasticity.	Nature of Fracture.
0·695	20·4	45·8		Silky.
0·697	19·2	48·0	Mean 0·348 28,740,000	Silky, a little laminated.
0·807	16·9	50·7		Do. do.
0·733	**18·8**	**48·2**		
0·835	18·0	46·0	Mean 0·328 30,490,000	Silky, granular.
0·692	18·4	51·7		Do. do.
0·738	22·0	49·3		Silky, slightly laminated.
0·755	**19·4**	**49·0**		
0·702	23·3	44·8	Mean 0·331 30,210,000	Silky, laminated; lamination partly crystalline; in part discoloured.
0·723	19·6	52·5		Silky, granular, slightly laminated; in part slightly discoloured.
0·747	21·2	40·8		Silky, slightly laminated.
0·724	**21·4**	**46·0**		
0·787	20·2	47·0	Mean 0·331 30,210,000	Silky, granular, small specks of crystal.
0·790	19·0	39·6		Silky.
0·724	15·6	42·5		Silky, granular.
0·767	**18·3**	**43·0**		

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ADDENDUM FROM MR. RALPH H. TWEDDELL.

I have carefully considered Professor Kennedy's able Report, and have also examined the figures in the Tables of experiments. The results are in accordance with what I myself anticipated; and where there exists any discrepancy, it arises I think from the fact of a riveting machine of the same power having been used for rivets 0·7 inch or 0·8 inch diameter, and also for rivets 1·1 inch diameter.

For example, the breaking stress in tons is as follows:—

In Table XXIX	Hand-Riveting .	86·01	tons.
	Hydraulic-Riveting	85·75	„
„ XXX	Hand-Riveting .	82·16	„
	Hydraulic-Riveting	82·70	„

or practically the same; but with the larger rivets of 1·1 inch diameter—

In Table XXXI	Hand-Riveting .	149·2	„
	Hydraulic-Riveting	145·5	„
„ XXXII	Hand-Riveting .	193·6	„
	Hydraulic-Riveting	183·1	„

In the last two cases the hand-riveted joint has the best of it. I think that this may be accounted for in two ways. First, the pressure applied by the riveting machine was too low; second, I think it is possible that the material itself, having already been tested to destruction in previous experiments (so far as the joints are concerned), was not quite equal to giving such good results on this occasion. Notwithstanding the above results, I consider, for all the practical purposes of a "joint"—especially for boiler work, where "tightness" is essential, and also for girder work or other structures subject to sudden strains—that the hydraulic riveting is very much superior to that done by hand. For example, taking the point at which visible slip commences:—

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Table.	Test No.	Hand-Riveting.	Hydraulic-Riveting.
XXIX	1480	20 tons.	45 tons.
XXX	1485	25 „	67 „
XXXI	1486	40 „	61 „
XXXII	1490	25 „	50 „

The above figures are all greatly in favour of the hydraulic method, and I think this is so without exception in the whole series of experiments; so that, whilst in some cases the results, so far as final breaking strain is concerned, are less favourable, yet, so far as the real strength of a joint is concerned, the hydraulic riveting is the best—taking the best joint to be that in which "visible slip" commences at the highest load. For example (Table XXIX):—

In test 1482,	hand-riveting,	slip commences at 20	tons.
„ „	„	joint breaks at 88½	„
„ „	hydraulic-riveting,	slip commences at 50	„
„ „	„	joint breaks at 87	„

Thus, while in the first of these the elastic limit is just about reached when slip commences, the second is strained far beyond this point, which would account for a less favourable breaking strain.

It is probable that some additional tests with a riveting machine of a similar power (in proportion to the 1·1 inch rivets) to that used in these experiments for the 0·7 inch and 0·8 inch rivets, would clear up any doubtful questions already referred to in this letter as to the results in Tables XXXI and XXXII.

So far as concerns the question of any difference in the results being due to the plates having already been tested, I think there would be more chances of differences arising from using another parcel of plates; and I am glad to accede to a suggestion of Professor Kennedy that the thinner plates should be cut and riveted up once more by hand, while the thicker plates should be cut and riveted by a hydraulic machine, but one large enough to give the full pressure for that size.

Although it has only an indirect bearing on the present experiments, I may mention that, so far as the tensile strength of a

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rivet is concerned, no benefit is to be found by exposing it to a higher closing pressure than that necessary to fill the hole completely. M. Marc Berrier-Fontaine informs me that he has made numerous experiments on this point, and with the above results. I do not think he has completed his experiments yet. He riveted two round plates AA and BB together, by means of the rivet C, Fig. 11, Plate 29. The plates were screwed on their outer surfaces to enable the clips of a testing machine to be readily attached. On being pulled apart in the machine, it took the same power to fracture the rivet, notwithstanding any increase of pressure employed in closing it.

20 *August* 1883. RALPH HART TWEDDELL.

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Letter from Mr. W. Silver Hall to Professor Alexander B. W. Kennedy.

I have carefully examined the answers that have been received from various boiler-makers, in reply to the recent circular from the Institution asking them what was the widest pitch of rivets that could be used without impairing the tightness of the joint under steam.

As regards single-riveted lap joints. Most of the replies merely contain examples of the ordinary and time-honoured proportions of riveting, and add no further information to that already tabulated by Mr. R. H. Tweddell (see Proceedings 1881, pp. 258 and 293). But Mr. C. H. Moberly sends a double Table of proportions, adopted by Messrs. Easton and Anderson as the result of certain experiments fully described in the Proceedings of the Institution of Civil Engineers, 1882, vol. lxix, p. 337.

In the first series of this Table, for maximum strength, the diameters of rivets, and consequently the pitch, are rather in excess of the proportions recommended by you in Proceedings 1881, p. 229.

In the second series, intended to be used for the circular seams of boilers which have longitudinal double-riveted lap joints, the proportions, except for plates $\frac{9}{16}$ inch thick, are almost exactly the same as those given by your formula, in which—

t = thickness of plate.
d = diameter (actual) of rivet in parallel hole.
p = pitch of rivets centre to centre.
l = overlap of plates.

$$d = t \times 2{\cdot}25$$
$$p = d \times 2{\cdot}25 = t \times 5 \text{ (very nearly)}$$
$$l = t \times 6$$

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For comparison, in the Table below are given the three sets of proportions, namely Mr. Moberly's first and second series (M_1 and M_2), and your own (K), all in inches :—

t	d			p			l		
	M_1	M_2	K	M_1	M_2	K	M_1	M_2	K
$\frac{3}{16}$	$\frac{1}{2}$	$\frac{7}{16}$	$\frac{7}{16}$	$1\frac{1}{8}$	$\frac{7}{8}$	$1\frac{5}{16}$	$1\frac{3}{16}$	1	$1\frac{1}{8}$
$\frac{1}{4}$	$\frac{5}{8}$	$\frac{9}{16}$	$\frac{9}{16}$	$1\frac{7}{16}$	$1\frac{3}{16}$	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{5}{16}$	$1\frac{1}{2}$
$\frac{5}{16}$	$\frac{13}{16}$	$\frac{11}{16}$	$\frac{11}{16}$	2	$1\frac{1}{2}$	$1\frac{9}{16}$	$2\frac{1}{16}$	$1\frac{5}{8}$	$1\frac{7}{8}$
$\frac{3}{8}$	$1\frac{5}{16}$	$1\frac{3}{16}$	$1\frac{3}{16}$	$2\frac{5}{16}$	$1\frac{13}{16}$	$1\frac{7}{8}$	$2\frac{3}{8}$	2	$2\frac{1}{4}$
$\frac{7}{16}$	$1\frac{1}{16}$	$1\frac{5}{16}$	1	$2\frac{5}{8}$	$2\frac{3}{16}$	$2\frac{3}{16}$	$2\frac{5}{8}$	$2\frac{5}{16}$	$2\frac{5}{8}$
$\frac{1}{2}$	$1\frac{3}{16}$	$1\frac{1}{16}$	$1\frac{1}{8}$	3	$2\frac{1}{2}$	$2\frac{1}{2}$	3	$2\frac{5}{8}$	3
$\frac{9}{16}$	$1\frac{5}{16}$	$1\frac{3}{16}$	$1\frac{1}{4}$	$3\frac{5}{16}$	$2\frac{9}{16}$	$2\frac{13}{16}$	$3\frac{3}{8}$	$2\frac{3}{4}$	$3\frac{3}{8}$

In this Table I have taken out the diameters of rivets in Mr. Moberly's proportions as accurately as can practically be done in the case of plates punched with tapering holes. The same proportions are also shown graphically in the sketch, Fig. 12, Plate 29.

It is evident from the above that by adopting your formula we shall obtain a set of working proportions suitable equally for boilers having double-riveted or single-riveted longitudinal seams, in conjunction with a diameter of rivet that is perfectly attainable in practice (of course with machine riveting); and that with good workmanship (and the specifying of a broad pitch compels good workmanship in a most effectual manner) there need be no fear of leakage with even a wider pitch than that recommended.

Both you and Mr. Moberly very properly point out that with an increased thickness of plates other considerations come in to modify the proportions above recommended.

The above remarks refer to boilers made with steel plates and steel rivets. Mr. Michael Longridge quotes an instance of a boiler with $\frac{3}{8}$-inch plates and $\frac{3}{4}$-inch rivets (probably $\frac{13}{16}$ inch

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actually), pitched $2\frac{1}{4}$ inches apart, working at 60 lbs. pressure; and of another with $\frac{1}{2}$-inch plates, diameter of rivets not given, rivets pitched $2\frac{7}{8}$ inches apart, centre to centre, working at 60 lbs. pressure: the material in both cases being iron.

As regards double-riveted lap joints, I am not aware that you have framed any definite formula; I have therefore constructed one as follows, from the result of your latest experiments:—the lap l in this case is equal to the lap of a single-riveted joint *plus* the space s between the pitch lines of rivets.

t = thickness of plate.
d = diameter (actual) of rivet in parallel hole.
p = pitch of rivets centre to centre.
s = space between lines of rivets.
l = overlap of plates.

$$d = 2{\cdot}25\ t \text{ (as before)}$$
$$p = 8\ t$$
$$s = 4{\cdot}5\ t$$
$$l = 10{\cdot}5\ t$$

The following is a comparative Table of the dimensions (F) given by this formula and those (M) adopted by Mr. Moberly, all in inches:—

t	d		p		s		l	
	M	F	M	F	M	F	M	F
$\frac{3}{16}$	$\frac{7}{16}$	$\frac{7}{16}$	$1\frac{1}{2}$	$1\frac{1}{2}$	$\frac{7}{8}$	$\frac{7}{8}$	$2\frac{1}{8}$	2
$\frac{1}{4}$	$\frac{9}{16}$	$\frac{9}{16}$	2	2	$1\frac{3}{16}$	$1\frac{3}{16}$	$2\frac{7}{8}$	$2\frac{3}{4}$
$\frac{5}{16}$	$\frac{11}{16}$	$\frac{11}{16}$	$2\frac{1}{2}$	$2\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{2}$	$3\frac{1}{2}$	$3\frac{3}{8}$
$\frac{3}{8}$	$\frac{13}{16}$	$\frac{13}{16}$	3	3	$1\frac{3}{4}$	$1\frac{3}{4}$	$4\frac{1}{8}$	4
$\frac{7}{16}$	$\frac{15}{16}$	1	$3\frac{1}{2}$	$3\frac{1}{2}$	2	2	$4\frac{3}{4}$	$4\frac{5}{8}$
$\frac{1}{2}$	$1\frac{1}{16}$	$1\frac{1}{8}$	4	4	$2\frac{5}{16}$	$2\frac{1}{4}$	$5\frac{1}{2}$	$5\frac{1}{4}$
$\frac{9}{16}$	$1\frac{3}{16}$	$1\frac{1}{4}$	$4\frac{1}{4}$	$4\frac{1}{2}$	$2\frac{1}{2}$	$2\frac{1}{2}$	$5\frac{7}{8}$	$5\frac{7}{8}$

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In Mr. Moberly's dimensions it would be of interest to know the reasons for adopting an increased margin between rivet hole and edge of plate in double-riveted seams, as compared with that which he finds sufficient in single-riveted seams.

The fact—suggested I believe by you to Mr. Moberly, and fully corroborated by the results of his experiments—that the strength of the metal is greater along the straight line than along the zigzag line, through the holes, is a most important one to bear in mind. If the strength were equal, s need only be equal to $t \times 3{\cdot}25$, and l equal to $t \times 9{\cdot}25$. This point, and in fact the whole question of double-riveted joints, and also of butt joints with double covers, is thoroughly gone into in Mr. Moberly's second paper (Proceedings Inst. Civil Engineers, 1883, vol. lxxii, p. 226).

The above remarks refer to steel plates and rivets. In iron boiler-work Mr. Michael Longridge gives the following examples:—

Mode of Riveting.	All in Inches.				Pressure. Lbs.
	t	d	p	s	
Hand	$\frac{3}{8}$	—	$3\frac{1}{2}$	$1\frac{1}{4}$	60
Hand	$\frac{3}{8}$	—	$3\frac{5}{8}$	$1\frac{1}{4}$	40
Machine	$\frac{3}{8}$	$\frac{3}{4}$	3	2	65
Machine	$\frac{7}{16}$	$\frac{3}{4}$	$3\frac{1}{4}$	$1\frac{1}{4}$	65

In this Table $\frac{1}{16}$ inch should probably be added to the diameter of the rivets.

It may therefore be fairly assumed, from the foregoing facts and figures, that no practical difficulty need be feared as to the tightness of joints set out according to the proportions suggested by you, and embodied in the formulæ and Tables given above.

It would be additionally interesting if Mr. Moberly would favour us from time to time with particulars as to the behaviour, after continued working, of the boilers built according to his proportions, and also as to any modifications which further experience may induce him to adopt.

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Among the letters, &c., received in reply to the circular recently sent out, there are some which contain very interesting information respecting the proportions adopted by different firms for butt joints with double covers and with double and treble riveting. Some of these will be found valuable at a further stage of the enquiry; but as they do not bear directly upon the question at present under consideration, namely the widest pitches at which tightness can be obtained, they need not now be taken into consideration.

May 1884. W. Silver Hall.

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RESEARCH COMMITTEE ON RIVETED JOINTS.

ABSTRACT OF RESULTS OF EXPERIMENTS ON RIVETED JOINTS, WITH THEIR APPLICATIONS TO PRACTICAL WORK.

BY PROFESSOR ALEXANDER B. W. KENNEDY, *Honorary Life Member.*

The Experiments of which the following is an abstract consist of fourteen series, numbered for reference I to V, VA, and VI to XIII, and covering in all 290 experiments, 64 on perforated (punched and drilled) plates, 97 on actual joints, 44 on the tenacity of the plates used in the joints, 33 on the tenacity and shearing resistance of the rivet steel used in the joints, and the rest on various other matters connected with them.

It will be well to summarise all the experiments in order first, reserving all remarks on their application to practical work until the end. It should be premised that all the joints in the whole series were supposed to be made of the same material, a soft steel or ingot iron, supplied from the Landore Siemens-Steel Works; and that all the rivets were made from rivet steel supplied from the same works.

The experiments of Series I, II, III, and IV (Proceedings 1881, pp. 206–214, Tables I to XI) were undertaken with the object of determining the principal constants with respect to the material used, and incidentally of settling some questions as to the best form to be given to the test specimens. The material itself was found to have a tenacity of from 28 to 30 tons per sq. inch, with an extension of 23 to 25 per cent. in a length of 10 inches. The limit of elasticity of the metal was generally about 60 per cent. of its ultimate resistance, but was over 70 per cent. in the case of the $\frac{1}{4}$-inch plates. The percentage of carbon in the plates was said to be about 0·18.

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It was found that increasing the width of the test piece from $1\frac{3}{8}$ inch to 4 inches in $\frac{1}{4}$-inch plate, or from 2 inches to $3\frac{1}{2}$ inches in $\frac{3}{8}$-inch plate, made no measurable difference either in the breaking load per sq. inch or in the extension in 10 inches after fracture. It was also found that the same results were obtained in these and other respects, whether the test pieces were pulled from pins or from wedge grips, special care being taken as to the centralisation of the pull in both cases.

Incidentally certain measurements were made in connection with the elasticity of the material and its small extensions at ordinary working loads; and the author believes that certain important points in connection with these matters were noted and described for the first time.

The tenacity of the rivet steel turned out to be practically the same as that of the plates (Series III, Tables VIII to X).

The shearing resistance of the rivet steel (three sizes) was measured in Series IV, Table XI. The apparatus employed has been already described and illustrated (Proceedings 1881, p. 214, Plate 30, Figs. 2 and 3). The experiments were made on *single* shear, to correspond with the following experiments on single-riveted joints. The mean result was 24·8 tons per sq. inch, the actual shearing being effected in rings of the steel plate of which the joints were to be made, their edges just touched with a file to ensure there being no burr. Mr. Schönheyder, in discussion, suggested (p. 268) that the apparatus used would give too high results, on account of induced friction in the blocks. The author found that the method suggested by Mr. Schönheyder gave results very much lower than those of his own apparatus (about 10 per cent.), but in each case with a certain amount of bending action in the rivet, which would naturally tend to lower the resistance to some unascertained extent. On the other hand, experiments were tried in which the piece tested was an actual rivet in place, the rings being turned out of the riveted-up plates. The apparatus was that originally employed, and although in such a case the tendency to side pressure in the blocks would probably be less than before, the

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loads at which the rivets sheared were greater than before, averaging as much as 26½ tons per sq. inch. The rivet steel in this case was the same size as that which had formerly given the lowest result, namely 23½ tons per sq. inch. Later experiments on *double* shear, with rivet steel supposed to be of the same quality, but with apparatus in which there could be no friction, gave as much as 26 tons per sq. inch as the shearing resistance under these conditions, which are those of many of the later series of experiments. The variations in the resistance of steel to shearing will be commented on later (p. 250).

Before proceeding to test actual riveted joints it was considered essential to test the plate perforated,—punched and drilled,—in order to see how far its strength was affected by this operation,—*i.e.*, to find the strength of the material in the actual form in which it is used in the joints. Experiments on this matter form Series V and VA, the latter a repetition set only, as the steel of Series V turned out to be harder than it was intended to use. In the result (1881, pp. 215–216, Tables XII to XV) it was found that with steel of about 30 tons tenacity, in the form of ¼-inch and ⅜-inch plate (unannealed, as in all the other experiments), drilled with holes 1 inch diameter and 2 inches pitch, the net metal between the holes had a tenacity 11 to 12 per cent. greater than that of the untouched plate. Even with *punched* holes the metal had a similar excess tenacity of over 6 per cent. With somewhat harder steel (34 tons in ¼-inch plate) this excess tenacity fell to 1·2 per cent. when the holes were punched, but remained as before for drilled holes. The diameter of the punched holes was assumed to be a mean between the measured diameters on each side of the plate.

It was not found to make any difference whether the bolster was 1-32nd or 3-32nds inch larger in diameter than the punch.

These experiments also showed that there was no difference to be found between pieces made 2 inches and pieces made 8 inches wide, if properly prepared—a result very fully borne out by subsequent experiments.

In order to see how far annealing would affect such plates as those used, although none of the experiments were made with

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annealed plates, the matter was tested, and the tenacity of the plate was found to be diminished only $3\frac{1}{2}$ per cent. by the process of annealing (p. 218).

The first experiments on actual riveted joints were those of Series VI,* (1881, pp. 219-222, Tables XVI to XVIII). This series consisted of twelve joints with two rivets each, all in $\frac{3}{8}$-inch plate, the joints being proportioned in pairs to break by tearing and shearing respectively. Four specimens were made with $\frac{1}{2}$-inch rivets, four with $\frac{3}{4}$-inch, and four with 1-inch, and two joints out of each four with narrow and two with wide pitch. The proportions of these joints were not intended to be those of practice, but such as should give to some extent limiting values for the resistances of the plate to tearing and of the rivets to shearing and pressure. The results were not very regular or satisfactory, some of the rivets shearing at very low loads—16 to 17 tons per sq. inch. From the results of all the experiments up till now, the author has no doubt that the shearing resistance of rivet steel is a quantity much more variable than the tenacity of steel plate or even than the tenacity of the rivet steel itself,—a result possibly due in some manner to the want of attention directed to this point, or of experiments specially upon it. In a general way the experiments of Series VI indicated that the excess of strength found in the perforated plates of Series V would be found also in the joints; and that a bearing pressure on the rivets of 36 to 40 tons per sq. inch would determine that a joint should give way by shearing, even if it did not reduce the shearing resistance of the rivets. This latter conclusion has not been found to be justified in the light of later experiments.

The point at which the joint commenced to open out was noted as carefully as the nature of the case allowed, and was found to be by no means proportional to the strength of the joint, but much more nearly a constant for all the joints, being 3·9 tons (total pull) for the smallest joints, and 4·95 tons† for the largest, the others

* It should be said that all the joints up to and including Series XI were hand-riveted.

† The breaking loads of these joints were about 7·5 and 28·5 tons (total) respectively.

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giving 4·8, 4·9, and 6·1 tons respectively. This behaviour of the joints is strikingly corroborated by later experiments, and will be further alluded to. In these single-riveted joints, actual slip of the plates did not occur until the load was much higher than that at which the opening of the joint became visible; but it is again noteworthy that the joints with $\frac{3}{4}$-inch and those with 1-inch rivets show commencement of visible slip at the same *total* load (about 10·2 tons), not at the same load per square inch.

Series VII contained six single-riveted lap-joints in $\frac{3}{8}$-inch plate, all with $\frac{3}{4}$-inch rivets; the first three had the same pitch, but varying "margin" (that is distance from edge of holes to edge of plate); the second three had the same margin, but varying pitch. The results are given in detail in pp. 222–224 and Tables XIX to XXI. It was concluded from these experiments that the margin need not be greater than the diameter of the rivet. All the joints broke by shearing the rivets, the mean shearing stress being 21·7 tons per square inch. The stress in the plate however was in several cases as much as 11 per cent. in excess of its natural tenacity when the rivets sheared, although the plate had not torn.

Having endeavoured by the aid of the experiments above summarised to obtain with sufficient accuracy the data necessary for proportioning single-riveted lap-joints in steel plate, the writer designed the joints of Series VIII (1881, pp. 224–229, Tables XXII to XXV). This series contained eighteen joints arranged in six sets of three each. The first set was intended to have such proportions as to be equally likely to give way by tearing the plate or by shearing the rivets. The intensity of the shearing stress was intended to be two-thirds of that of the tensile stress, while the bearing pressure was intended to be about 7½ per cent. greater than the tension. Other sets were made with excess and defect of plate area, excess and defect of rivet area, and excess of bearing pressure respectively, the different proportions being arrived at by varying the pitch and diameter of the rivets, and in the last case by varying the thickness of the plate also. The margin in all cases was $\frac{3}{4}$ inch. The proper proportions of the joints were somewhat interfered with

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by the fact that the thickness of the plates was rather greater than it should have been; but practically the series furnished all the information which it was intended to give.

The joints, Nos. 652, proportioned for uniform strength (and therefore for maximum strength, as long as the assumed bearing pressure was not exceeded) gave way in the rivets at 21·5 tons per square inch, the plates standing a stress 7 per cent. in excess of their natural tenacity without breaking. The same rivet steel tested for shearing resistance stood a stress of 26·3 tons per square inch before it broke. The decrease of strength in the joint can be well understood when it is remembered how much tensile stress, in addition to the shear, is caused in the rivets by the bending of the joint as it opens out when stretched. The "efficiency" of the joint, or proportion borne by its strength to the strength of the solid plate, was 55·1 per cent. The strongest joints of the series were those proportioned with excess of bearing pressure, Nos. 657; for it was found that the bearing pressure here allowed (40 tons per square inch) was *not* sufficient to weaken the joint in any way, and of course it allowed of an increase of pitch for the given diameter of rivet, and consequent increase of breadth of net plate in a given breadth of joint. All three of these joints gave way by the shearing of the rivets, the average shearing stress being 22 tons per square inch; but as the stress in the plate was 11 per cent. greater than the natural tenacity of the plate, it may fairly be taken that the joints were of nearly uniform strength in plate and rivets, although only the latter actually gave way. The mean efficiency of these three joints was 61 per cent., the highest single result being nearly 64 per cent. As only the averages of the results of each set of three were given in Table XXIII, it has been thought worth while to append a new Table (No. XXXIV, pages 260–261) giving the results of each single experiment as well as the averages. It is probable that the efficiency of these joints is as great as that of any single-riveted joint in the same material can be made, unless a higher bearing pressure on the rivets were to be allowed. This however would make a very considerable difference. For instance, if a pressure of 50 tons per square inch were allowable, rivets could be used of

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1·1 inch diameter in $\frac{3}{8}$-inch plate, giving a joint of probably 70 per cent. efficiency. It is not said that it would be advisable to do this; but it is merely pointed out how much such proportions, if practicable, would increase the efficiency of a joint.

The question of excess tenacity was well illustrated in this series of experiments. Three joints were made, as has been mentioned, with defect of plate area as compared with that of the rivets. In these joints (Nos. 656, 1 to 3) the pitch of the rivets was only 1·9 times the diameter of the holes, the rivet area being therefore 1·72 times the plate area: instead of under 1·5 times, as in the joint designed for uniform strength. In spite of this, the absolute strength of these joints was second only to that of those with the higher bearing pressure just mentioned. Their average efficiency was 58·6 per cent., and one of them actually broke in the rivets instead of in the plate. The cause of this remarkable result was that the very narrow bridge of plate left between the holes when the pitch was so much reduced developed the extraordinary amount of 23·2 per cent. excess tenacity, the stress in the plates at fracture being over 36 tons per square inch, while strips from the same plate had a resistance of only 29·4 tons per square inch.

All the joints in Series VIII were seven pitches in breadth, and had seven rivets in them. They were tested at Barrow. It is very satisfactory that their results corroborate so well the previous tests with much narrower joints and on a totally different machine.

Visible slipping of the two plates of the joint, one on the other, was observed to begin at about 24 per cent. of the load which broke the joint.

Series IX (1881, pp. 712–716, Tables XXVI and XXVII) contained twenty-one joints in $\frac{3}{4}$-inch plate, designed to compare with the $\frac{3}{8}$-inch joints of Series VIII. It was considered sufficient however to make each joint with two rivets only. All the joints were made out of one plate of Landore steel, the tenacity of which was found to be 27·3 tons per square inch, with an extension of over 27 per cent. in 10 inches,—a remarkably ductile plate for its thickness. These experiments corroborated in a very striking way

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those of Series VIII, and added one or two new results as well. The diameter of the rivet holes in the joints proportioned for uniform strength, Nos. 1233 and 1238, was taken as 1·1 inch, not because this was the best diameter, but because it was thought to be the largest diameter which would probably be actually employed in practice. These joints, which were intended to be equally likely to give way by shearing and tearing, went by tearing the plate in all cases. There were six of them; in three (Nos. 1233) the plate was pulled *along* and in three (Nos. 1238) *across* the direction in which it had been rolled; and all six gave results practically identical. The plate tore at a stress about 9 per cent. in excess of its natural tenacity, the shearing stress on the rivets being then about 20 tons per square inch. It was thought by some members of the Committee that this result might be improved by the use of heavier rivets; for those employed had been only of ordinary dimensions, and somewhat scant in heads and ends for holding together such thick plates. Messrs. Penn and Sons, who had made the joints, therefore cut off the strained ends of three of the joints, and re-riveted them with the heaviest rivets which it was thought possible to make sound by hand. These rivets weighed 1·2 lb. each, against 0·88 lb. the weight of the former ones. The result was very striking (Nos. 1382). The plates were so much better held together that they were still unbroken when the full shearing resistance of 22 tons per square inch was reached, and the joints broke by shearing instead of tearing, the stress in the (unbroken) plates being 32·2 tons per square inch, or 18 per cent. in excess of the tensile resistance of plain pieces. The efficiency of the joint was raised from 49 up to 53 per cent.

The general conclusions to be drawn from this set of experiments are probably these. (i) That a single-riveted joint in $\frac{3}{4}$-inch steel plate cannot have an efficiency much exceeding 50 per cent., unless rivets of a larger diameter than 1·1 inch are used. (ii) That with rivets of any diameter a very great increase of strength is obtained by increasing the amount of metal in the heads and ends of the rivets. Treating the rivets as of bar 1·05 inch diameter, and calculating from their weights, it will be seen that the rivets first used were equivalent to a straight bar long enough to fill up the hole in the

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two plates, and leave a length equal to 1·9 diameters over for forming head and end; while those used last had a length of 3·1 diameters available for the same purpose. This difference was sufficient to increase the efficiency of the joint from 49 to 53 per cent., that is 8 per cent. of the first-named quantity. (iii) That plate such as has been used for these joints makes as strong a joint crossways of the "grain" as lengthways, a fact of course of importance in connection with the plating of boilers, as well as with the arrangement of butt straps generally, which are so often strained across the direction in which they have been rolled.

Slipping of the plates in the joints occurred at loads even lower than in the former cases, becoming visible at 16 per cent. of the breaking load in the joints in which there was excess of plate area, and only reaching 20 per cent. of the breaking load in the joints where the rivet area was proportionately the largest. Practically therefore slip occurred at the *same absolute load* as in the $\frac{3}{8}$-inch joints of Series VIII, and not at an increased load proportional to the increased absolute strength of the joint.

It became evident at this stage of the enquiry that, although the earlier experiments had given sufficient information as to the resistance of the plate to tension and of the rivets to shear, the effect of bearing pressure still remained very much unknown. To obtain further information on this point the experiments of Series X were undertaken (1882, pp. 138–142). This series consisted of eight single-riveted lap-joints, four of $\frac{1}{4}$-inch and four of $\frac{3}{8}$-inch plate, these joints being made from specimens formerly used in Series V and VA, their fractured ends parted off, and the unstrained parts riveted together. The exact strength of the pieces tested, as well as the increase of strength due to perforation, were thus known from the former experiments. The result of these experiments is given in Table XXVIII. In the four joints of $\frac{1}{4}$-inch plate an average pressure of 53·5 tons per square inch on the net rivet surface (diameter × thickness) was reached, at which pressure the joint broke by shearing the rivets at a stress of 16·6 tons per square inch—a reduction of resistance clearly to be attributed to the heavy pressure. In the four joints of

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$\frac{3}{8}$-inch plate the average pressure at fracture was 46 tons per square inch, and only one joint went by shearing, the others all tearing across the plate. The joint which failed in the rivets sheared at 18·1 tons per square inch when the stress in the plate was about 28 tons per square inch. The three others broke at the average stress of 30·3 tons per square inch in the plate, the average strength of the same plates unperforated having been found to be 29·7 tons per square inch. Thus the high pressure seems to have prevented the full excess tenacity (of 10 to 12 per cent.) from being reached, although it did not actually weaken the plate below its normal resistance. The high pressure was visibly accompanied by an irregular giving way of the joints in several cases, contrasting markedly with the sudden and, so to speak, homogeneous way in which all the former joints had broken; and this method of fracture corresponded well with the lower breaking load.

It was considered that these experiments showed that it was practically inexpedient to design a joint in which the bearing pressure on the rivets should exceed 42 or 43 tons per square inch; and that it was important, whenever a large bearing pressure was used, to give the joint a *margin* of extra breadth, so as to prevent distortion, and consequent local inequalities of stress, as much as possible.

In Series XI, XII, and XIII (1885, pp. 198–217, Tables XXIX to XXXIII), double-riveted joints, lap and butt, were tested. These joints were not arranged, as before in Series IX, to break in different ways. It was thought that the earlier experiments had determined the necessary constants with sufficient completeness to allow of these joints being designed at once so as to be the strongest possible of the given type, and in the given thickness of plate, with rivets of the assumed diameter. Such joints should of course be equally likely to break in the plate or in the rivets. In their design however it had to be remembered that with a high bearing pressure, such as might occur in the butt joints, the rivets might shear under a stress greatly less than their normal resistance. The joints were thus girder joints rather than boiler joints, the latter class requiring

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excess of plate area (on account of the weakening effect of corrosion) rather than equal resistance of plates and rivets.

Series XI consisted of twelve joints, hand-riveted, to compare with the former experiments. Six of the joints were in $\frac{3}{8}$-inch and six in $\frac{3}{4}$-inch plate; and three of each six were lap and three were butt joints. The double-riveted lap-joints in $\frac{3}{8}$-inch plate (Table XXIX) gave an efficiency of nearly 81 per cent., and turned out to be of equal strength in plate and rivets. The rivets were 0·8 inch diameter (or 2·1 times the thickness of plate), their pitch 3·6 times their diameter, the net area of plate zigzag 29 per cent. greater than the net area straight across. The plate tore under a stress 10 per cent. in excess of its original resistance, and the rivets at the same time stood 24 tons per square inch without shearing, giving way in one case at 24·8 tons per square inch, while the plate remained unbroken at 34 tons. (Its natural strength was just 30 tons per square inch.)

The double-riveted butt-joints (Table XXX) also gave an efficiency of 80 per cent. The rivets were 0·7 inch diameter, pitched nearly 4 diameters apart, the zigzag area 27 per cent. greater than the straight. These were also probably very nearly joints of maximum strength; for although none gave way by shearing, yet the bearing pressure was 42 tons per square inch when the joints broke, and the shearing stress was then 15 tons per square inch.* The excess strength of the plate, in spite of the very large distance between the rivet holes, was still as much as 6·6 per cent.

The double-riveted lap-joints in $\frac{3}{4}$-inch plate (Table XXXI) turned out also to be of very nearly uniform strength, and had an efficiency of 71 per cent. They were made with rivets 1·1 inch diameter, pitched 2·8 diameters apart. The zigzag area was about 35 per cent. in excess. The plates tore at 31·2 tons per square inch, an excess resistance of 7·8 per cent. The rivets stood 22·2 tons per square inch without shearing. The bearing pressure in this case was (inevitably) quite low.

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* Series X showed that under a bearing pressure of 50 tons per square inch the rivets would have a shearing resistance of only 16 or 17 tons per square inch.

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The double-riveted butt-joints in $\frac{3}{4}$-inch plate (Table XXXII) proved unexpectedly to be proportionately too weak in the plate, partly because the natural strength of the plate itself was less than that of the plates used for the other joints, partly because the strength of the perforated plate turned out to be *less*, and not more, than that of the plate in its natural condition. This result corresponds with the crystalline fracture and apparent hardness of the material of the broken joints, but is not fully explained. The efficiency of these joints turned out to be 71·3 per cent. in spite of this. The plates tore at 26·5 tons per square inch when the stress in the rivets was 16·8 tons, and the bearing pressure about 40 tons per square inch. The rivets used were 1·1 inch diameter, pitched 4 diameters apart; excess of zigzag area 26 per cent. With plate of the same quality as the others, the efficiency of such joints would probably be at any rate 75 per cent.

Series XII consisted of the same joints as Series XI, the strained ends cut off and the rest re-drilled and riveted, but riveted this time by Mr. Tweddell's hydraulic machines. Series XIII contained also the same joints treated a second time in the same way. So far as strength goes, the hydraulic-riveted joints in $\frac{3}{8}$-inch plate in Series XII were identical with those of Series XI. In Series XIII the similar joints gave somewhat lower results, the main difference being due to the fact that a weaker quality of rivet steel was used, and the joints gave way by shearing the rivets. The hydraulic-riveted joints in $\frac{3}{4}$-inch plate, Series XII and XIII, gave way in all cases at a somewhat lower load than the similar hand-riveted joints, a difference due in the lap joints entirely to the weaker rivet-steel used, but not to be so explained in the case of the butt joints. It was found that both these sets of joints had been riveted up, through a misunderstanding, at a pressure much lower than that intended by Mr. Tweddell. Experiments are now in hand which, it is hoped, will settle any question as to the effect of high pressure in riveting.

Although these experiments, *so far as they went*, showed no gain of ultimate strength to result from hydraulic riveting as compared with good hand-riveting, they yet showed the former to possess enormous advantages in the shape of increase of the load at which

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slipping occurs, which, probably enough, is proportional to the load at which leakage might occur in a boiler. In the hand-riveted joints it was found that visible slip occurred always at about the same absolute load (average 26 tons); and this load was not at all proportional to the strength of the joint, being about 27 per cent. of the breaking load in the $\frac{3}{8}$-inch joints and about 16 per cent. in the $\frac{3}{4}$-inch joints. It will be noticed that in both cases these percentages are very close to those already given by the $\frac{3}{8}$-inch joints of Series VIII, and the $\frac{3}{4}$-inch joints of Series IX. In the hydraulic-riveted joints the same peculiarity occurs, somewhat less markedly, but with the vital difference that the load at which it occurs is about *twice as great*, namely 51 tons instead of 26, being 59 per cent. of the breaking load in the $\frac{3}{8}$-inch joints and about 28 per cent. in the $\frac{3}{4}$-inch. It has long appeared to the writer impossible that in joints which distort so much as these before fracture the hydraulic riveting should have any sensible influence on the breaking load (so long as the size of the rivet is not such as to render sound hand-riveting impossible); but he has maintained that its value lay in increasing the initial stiffness of the joints, a matter of at least equal and probably of greater importance. This view seems to be very fully confirmed by the results of the present observations. The whole question of hydraulic and hand-riveting however will be better discussed when the results of the experiments of Series XIV (high-pressure riveting, large rivets, thick plates), which are now in progress, can be laid before the Institution.

Conclusions.

Having now summarised the experiments themselves, we may proceed to summarise the conclusions which it appears safe to draw from them, to examine the proportions of joint which they appear to indicate as the best, and to mention the points on which further information is now being obtained. In accordance with the plan pursued in the rest of this abstract, this will be done in the briefest possible manner, without discussing the points at length as they occur. In most cases a much more detailed treatment of

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them will be found in the various reports of the Riveting Committee of which this is only an abstract. It will be remembered, and may be again stated here once for all, to avoid repetition, that the conclusions given below all refer to joints made in soft steel plate with steel rivets, that the holes were all drilled, and that the plates were in their natural state (unannealed).

Further it should be said that all dimensions, thicknesses of plate, &c., were measured by the most accurate means available; and that in every case the rivet or shearing area has been assumed to be that of the *holes*, not the nominal (or real) area of the rivets themselves. Also in every case the strength of the metal in the joint has been compared with that of strips cut from the same plates, and not merely with nominally similar material. It is thought that, if these points had always been attended to, many of the discrepancies in published riveted-joint experiments would never have appeared.

(i) The metal between the rivet holes has a considerably greater tensile resistance per square inch than the unperforated metal. This excess tenacity amounted to more than 20 per cent., both in $\frac{3}{8}$-inch and $\frac{3}{4}$-inch plates, when the pitch of the rivet was about 1·9 diameters. In other cases $\frac{3}{8}$-inch plate gave an excess of 15 per cent. at fracture with a pitch of 2 diameters, of 10 per cent. with a pitch of 3·6 diameters, and of 6·6 per cent. with a pitch of 3·9 diameters; and $\frac{3}{4}$-inch plate gave 7·8 per cent. excess with a pitch of 2·8 diameters.

(ii) The shearing resistance of the rivet steel is a matter upon which, as has been pointed out, further experiment is required. It may be taken as established that the resistance per square inch in double shear is as great as that in single shear, so that allowance need not be made for the two shearing planes not being equally stressed. In *single*-riveted joints however, the bending of the plates will put considerable tensile stress in the rivets; and this may diminish their apparent shearing resistance. In single-riveted joints it may be taken that about 22 tons per square inch is the

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shearing resistance of rivet steel,* when the pressure on the rivets does not exceed about 40 tons per square inch. In double-riveted joints, with rivets of about $\frac{3}{4}$ inch diameter, most of the experiments gave about 24 tons per square inch as the shearing resistance, but the joints in Series XIII went at 22 tons. In Series XIII the larger rivets also went at a low load; but in the other double-riveted joints with large rivets these latter remained unbroken at a stress of 22 tons per square inch. There are appended in Table XXXV, page 262, the results of a number of recent experiments on the shearing resistance of steel of various qualities, which may prove interesting. These show distinctly that the ratio of shearing resistance to tenacity is not constant, but diminishes very markedly and not very irregularly as the tenacity increases. All the experiments given in this table were made in double shear, with test pieces of the form shown in Fig. 10, Plate 29.

(iii) The size of the rivet-heads and ends plays a most important part in the strength of the joints, at any rate in the case of single-riveted joints. An increase of about one-third in the weight of the rivets (all this increase, of course, going to the heads and ends) was found to add about 8½ per cent. to the resistance of the joint, the plates remaining unbroken at the full shearing resistance of 22 tons per square inch, instead of tearing at a shearing stress of only a little over 20 tons.† The additional strength is probably due to the prevention of the distortion of the plates by the great *tensile* stress in the rivets.

(iv) The strength of a joint made *across* a plate is equal to that of one made in the usual direction. (Both this conclusion and the last preceding are stated as the result of a very limited number of experiments; but there seems no reason to doubt their general truth.)

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* In one pair of single-riveted joints only (Nos. 383 and 384 in Table XVII of Series VI) a shearing resistance of over 24 tons per square inch was reached; in none of the others did it exceed 22·5 tons.

† See Proceedings 1881, pp. 713–714, and Table XXVI.

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(v) The intensity of bearing pressure on the rivets exercises, with joints proportioned in the ordinary way, a very important influence on their strength. So long as it does not much exceed 40 tons per square inch (measured on the projected area of the rivets) it does not seem to affect their strength; but pressures of 50 to 55 tons per square inch seem to cause the rivets to shear in most cases at stresses varying from 16 to 18 tons per square inch. This conclusion is based on the experiments of Series X, in which the *margin* was made equal to the diameter of the drilled hole. For ordinary joints, which are to be made equally strong in plate and in rivets, the bearing pressure should therefore probably not exceed 42 or 43 tons per square inch. For double-riveted butt-joints perhaps, as will be noted later, a higher pressure may be allowed, as the shearing stress may probably not exceed 16 or 18 tons per square inch when the plate tears. But in this case it would probably be wise to increase the margin.

(vi) A margin (or net distance from outside of holes to edge of plate) equal to the diameter of the drilled hole has been found sufficient in all cases hitherto tried.

(vii) To attain the maximum strength of a joint, the breadth of lap must be such as to prevent it from breaking zigzag. Such a method of fracture must inevitably be accompanied by unequal stresses in the plate straight between the rivet-holes, and by consequent diminution of strength. It has been found that the net metal measured zigzag should be from 30 to 35 per cent. in excess of that measured straight across, in order to ensure a straight fracture. This corresponds to a diagonal pitch of $\frac{2}{3}p + \frac{d}{3}$, if p be the straight pitch and d the diameter of the rivet-hole. To find the proper breadth of lap for a double-riveted joint, it is probably best to proceed by first setting this pitch off, and then finding from it the longitudinal pitch, or distance between the centres of the lines of rivets.

(viii) Visible slip or "give" occurs always in a riveted joint at a point very much below its breaking load, and by no means

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proportional to that load. A careful collation of all the results obtained in measuring the slip indicates pretty clearly that it depends upon the number and size of the rivets in the joint, rather than upon anything else; and that it is tolerably constant for a given size of rivet in a given type of joint. The loads *per rivet* at which a joint will commence to slip visibly are *approximately* as follows:—

Diameter of Rivet.	Type of Joint.	Riveting.	Slipping Load per rivet.
¾ inch	Single riveted	Hand	2·5 tons
,,	Double riveted	Hand	3·0 to 3·5 tons
,,	Double riveted	Machine	7 tons
1 inch	Single riveted	Hand	3·2 tons
,,	Double riveted	Hand	4·3 tons
,,	Double riveted	Machine	8 to 10 tons

To find the probable load at which a joint of any breadth will commence to slip, it is only necessary to multiply the number of rivets in the given breadth by the proper figure taken from the last column of the Table above. It will be understood that the above figures are not given as exact; but they represent very well the results of the experiments in all series from VIII to XIII: except series X, in which the average (for 1-inch rivets) was much lower than that given above. In this series however the proportions of the joints were intentionally somewhat abnormal; and it is perhaps not to be expected that in this respect their results should agree with those of the other experiments.

This result as to the slipping of a joint, although perhaps unexpected, is not contrary to what ought to have been expected. For experiments show that, long before stresses are reached which could visibly stretch the plates of a joint, there will be quite measurable shear of the rivet. The visible slip therefore will consist almost wholly of this shear, the magnitude of which will depend primarily on the number and size of the rivets in the joint. Anything that will hold the plates up better together, such as hydraulic pressure on the rivets, might be expected to diminish this shear or to delay its commencement, exactly as seems to have happened. The following Table gives the result of experiments on this matter

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which were made along with those given in the Committee's first Report, but which have not previously been published in the Proceedings of the Institution. The experiments are on 1-inch turned pins of rivet steel, tested in the single-shear apparatus already described. Of course the shear would commence later, and be at first smaller in extent, when the pin was replaced by an actual rivet, and when the plates were thus forcibly held together, instead of being quite free to slide, except so far as held from motion by the resistance to shear.

Shearing Stress in Lbs. per square inch.	Test Nos. :—					
	343	344	345	346	347	348
	Amount of Shear in Inches.					
0	0·0	0·0	0·0	0·0	0·0	0·0
6,365	·010	·013	·016	·022	·055	·021
12,730	·022	·028	·030	·034	·066	·032
19,100	·034	·040	·042	·048	·078	·043
25,460	·055	·060	·060	·071	·091	·062
28,320	·066	—	—	—	—	—
31,830	·080	·086	·082	·091	·113	·083
35,010	·093	—	—	—	—	—
38,190	·113	·113	·108	·114	·140	·108
41,380	·141	—	—	—	—	—
44,550	·168	·152	·142	·170	·171	·155
47,740	·200	—	—	—	—	—
50,910	·242	·200	·196	·248	·238	·222
54,110	—	—	—	—	—	—
Breaking Load Lbs. per sq. inch Tons	54,110 24·15	54,930 24·52	55,240 24·66	52,830 23·59	56,670 25·29	53,530 23·90

(ix) The value of hydraulic riveting as compared with hand-riveting, in cases when sound hand-riveting is possible, lies mainly, if not entirely, in the fact that it doubles the load at which the slip of a joint commences. This conclusion is subject to modification by future experiments with the use of higher pressures in closing the rivet, which may probably still further raise the slipping load, so that the advantage of hydraulic riveting may quite possibly be even greater than it is here assumed to be; but there is no indication that it is likely to affect the ultimate strength of the joint. The question of *friction* in the joint, which has not been specially experimented on

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by the Committee, no doubt comes in in the same way. The friction induced by the rivet will affect the point at which slip commences; but can hardly have much, if any, relation to the breaking load.

It is thought that the load at which visible slip commences is probably proportional to the load at which leakage would begin in a boiler. Looked at in this way, it will be seen that the great value of hydraulic riveting appears to lie rather in the increased security and stiffness it gives at ordinary working loads than in any actual raising of the breaking load. From a practical point of view the former is probably the more, and not the less, important function.

Further experiments are now in progress to test the effect of higher closing pressures on the rivet than were used in Series XII and XIII, the results of which, it is hoped, will allow more definite conclusions to be arrived at in respect to the comparative merits of hydraulic and hand-riveting.

(x) The experiments point to very simple rules for the proportioning of joints of maximum strength, which will be mentioned before any other joints are discussed. Assuming that a bearing pressure of 43 tons per square inch may be allowed on the rivet, and that the excess tenacity of the plate is 10 per cent. of its original strength,* the following short Table gives the values of the ratios of diameter d of hole to thickness t of plate ($\frac{d}{t}$), and of pitch p to diameter of hole ($\frac{p}{d}$), in joints of maximum strength in $\frac{3}{8}$-inch plate.

Original Tenacity of Plate. Tons per sq. inch.	Shearing Resistance of Rivets. Tons per sq. inch.	Ratio $\frac{d}{t}$	Ratio $\frac{p}{d}$	Ratio $\frac{\text{Plate Area}}{\text{Rivet Area}}$
30	22	2·48	2·30	0·667
28	22	2·48	2·40	0·785
30	24	2·28	2·27	0·713
28	24	2·28	2·36	0·690

* The excess strength is taken lower than the average result of the experiments, because it is probable enough that the steel used had more than the average softness.

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Summed up and rounded off, this Table shows that the diameter of the *hole* (not the diameter of the rivet cold) should be $2\frac{1}{3}$ times the thickness of the plate, and the pitch of the rivets $2\frac{3}{8}$ times the diameter of the hole.* In mean also it makes the plate area 71 per cent. of the rivet area.

If a smaller rivet be used than that here specified, the joint will not be of uniform and therefore not of maximum strength; but with any other size of rivet the best result will be got by use of the pitch obtained from the simple formula formerly cited,

$$p = a\frac{d^2}{t} + d$$

where, as before, d is the diameter of the hole.

The value of the constant a in this equation is as follows:—

For 30-ton plate	and	22-ton	rivets,	a =	0·524
„ 28	„	22	„	„	0·558
„ 30	„	24	„	„	0·570
„ 28	„	24	„	„	0·606

or in the mean, the pitch $p = 0{\cdot}56\frac{d^2}{t} + d$.

It should be noticed that with too small rivets this gives pitches often considerably smaller in proportion than $2\frac{3}{8}$ times the diameter.

For double-riveted lap-joints a similar calculation to that given above, but with a somewhat smaller allowance for excess tenacity on account of the large distance between the rivet-holes, shows that for joints of maximum strength the ratio of diameter to thickness should remain precisely as in single-riveted joints; while the ratio of pitch to diameter of hole should be 3·64 for 30-ton plates and 22 or 24-ton rivets, and 3·82 for 28-ton plates with the same rivets.

Here, still more than in the former case, it is likely that the prescribed size of rivet may often be inconveniently large. In this case the diameter of rivet should be taken as large as possible; and the strongest joint for a given thickness of plate and diameter of hole can then be obtained by using the pitch given by the equation

$$p = a\frac{d^2}{t} + d,$$

* The small difference here from the constants formerly given is due to the assumption, now quite justified, of a somewhat greater bearing pressure than was then allowed.

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where the values of the constant a for different strengths of plate and rivets may be taken as follows :—

TABLE OF PROPORTIONS OF DOUBLE-RIVETED LAP-JOINTS,

IN WHICH $p = a\frac{d^2}{t} + d$

Thickness of Plate.	Original Tenacity of Plate. Tons per sq. inch.	Shearing Resistance of Rivets. Tons per sq. inch.	Value of Constant a.
$\frac{3}{8}$-inch	30	24	1·15
„	28	24	1·22
„	30	22	1·05
„	28	22	1·12
$\frac{3}{4}$-inch	30	24	1·17
„	28	24	1·25
„	30	22	1·07
„	28	22	1·14

Practically we may say that, having assumed the rivet diameter as large as possible, we can fix the pitch as follows, for any thickness of plate from $\frac{3}{8}$ to $\frac{3}{4}$ inch :—

For 30-ton plate and 24-ton rivets
„ 28 „ 22 „ } $p = 1{\cdot}16\frac{d^2}{t} + d$

„ 30 „ 22 „ $p = 1{\cdot}06\frac{d^2}{t} + d$

„ 28 „ 24 „ $p = 1{\cdot}24\frac{d^2}{t} + d$

In double-riveted butt-joints it is impossible to develop the full shearing resistance of the joint without getting excessive bearing pressure, because the shearing area is doubled without increasing the area on which the pressure acts. In the writer's last report it was shown that, considering only the plate resistance and the bearing pressure, and taking this latter as 45 tons per square inch, the best pitch would be about 4 times the diameter of the hole. It appears justifiable however to apply here the results of Series X, and take corresponding constants. Thus we may probably say with some certainty that a pressure of from 45 to 50 tons per square inch on the rivets will cause shearing to take place at from 16 to 18 tons per

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square inch. Working out the equations as before, but allowing excess strength of only 5 per cent. on account of the large pitch, we find that the proportions of double-riveted butt-joints of maximum strength under given conditions are those of the following Table:—

Original Tenacity of Plate. Tons per sq. inch.	Shearing Resistance of Rivets. Tons per sq. inch.	Bearing Pressure. Tons per sq. inch.	Ratio $\frac{d}{t}$	Ratio $\frac{p}{d}$
30	16	45	1·80	3·85
28	16	45	1·80	4·06
30	18	48	1·70	4·03
28	18	48	1·70	4·27
30	16	50	2·00	4·20
28	16	50	2·00	4·42

Practically therefore it may be said that we get a double-riveted butt-joint of maximum strength by making the diameter of hole about 1·8 times the thickness of the plate, and making the pitch 4·1 times the diameter of the hole. These are very nearly the proportions which were used for the $\frac{3}{8}$-inch joints in Series XI to XIII; for the $\frac{3}{4}$-inch joints the diameter of the rivet was (as with the lap joint) less than that indicated by theory. In thick plates, where it is thought impossible or inconvenient to make the rivet-holes so large as 1·8 times the thickness, the best pitch for any assumed diameter of rivet cannot be found by the method formerly used; for here we have not a given maximum shearing stress to work to, but rather the shearing stress which in a given joint causes a given maximum pressure on the rivets. The best ratio of pitch to diameter of hole in double-riveted butt-joints of maximum strength for *any* assumed diameter of hole is therefore the same as that given in the last Table, or in mean 4·1.

(xi) All the experiments hitherto made have necessarily connected themselves with the question of *strength*, and the proportions just given belong to *joints of maximum strength*. But in a boiler the one part of the joint, the plate, is much more affected by time than

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the other part, the rivets. It is therefore not unreasonable to estimate the percentage by which the plates might be weakened by corrosion &c. before the boiler would be unfit for use at its proper steam pressure, and to add correspondingly to the plate area. Probably the best thing to do in this case is to proportion the joint not for the actual thickness of plate, but for a nominal thickness less than the actual by the assumed percentage. In this case the joint will be approximately one of uniform strength by the time it has reached its final workable condition: up to which time the joint as a whole will not really have been weakened, the corrosion only gradually bringing the strength of the plates down to that of the rivets. Thus, suppose a single-riveted lap-joint in $\frac{5}{8}$-inch plate is in question, and it is considered that corrosion will make this equal to only a $\frac{1}{2}$-inch plate before the boiler pressure has to be lowered. The rivet should then be proportioned as if the plate had a thickness of 0·5 inch, which would give, for 30-ton plate and 22-ton rivets (see Table on p. 254) a diameter of hole of 1·24 inch. Assume this as too large to be convenient, and take the diameter of hole as 1 inch. Then from the Table on p. 255 the pitch will be

$$p = \frac{0{\cdot}524}{0{\cdot}5} + 1 = 2{\cdot}05 \text{ inches.}$$

The ratio of plate to rivet area to start with will be 0·835, which means of course that the plate is in excess; but the ratio will diminish until it reaches 0·667 when the strength of the plate has become equivalent to that of one only $\frac{1}{2}$ inch thick, as was required. The efficiency of the joint would be 45 per cent., whereas the best efficiency of a joint in $\frac{5}{8}$-inch plate with 1-inch holes (p = 1·84 inches) would be 50 per cent., and the best possible efficiency of a single-riveted lap-joint in $\frac{5}{8}$-inch plate under the given condition of strength would be about 62 per cent.

It is hardly necessary to point out how strongly these figures indicate the necessity of using as large rivets as possible, and of taking every possible means to reduce the allowance necessary for corrosion. For a boiler such as has just been discussed is absolutely no stronger than one of $\frac{1}{2}$-inch plate throughout, if only the thickness of the latter could be kept unreduced at the joints.

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(xii) There are now in hand for the Riveting Committee further experiments on double-riveted joints of the general types already tested, in $\frac{3}{8}$-inch, $\frac{3}{4}$-inch, and 1-inch plate, designed specially to throw light upon the questions of hydraulic and hand-riveting, high and low pressure hydraulic-riveting, and the practical value of exceptionally large rivets. They will also give further information as to the slip of joints, and other points already discussed; and may further, it is hoped, be made use of to throw some light on rather more obscure problems (such as those raised recently by Mr. Milton at the Institution of Naval Architects) connected with he stress in the metal of the plate in the neighbourhood of the joint.

For the sake of more convenient reference, a Table has been prepared and is appended (Table XXXVI, page 263), giving the purpose of each series of experiments, and other particulars connected with the whole.

Although this paper is an unofficial abstract of the result of experiments only, and not an official summary of the whole work of the Riveting Committee, the author may be allowed to call attention in conclusion to the other memoirs, not reports on experiments, which have been prepared in connection with the work of the Committee. Of these the earliest, and by far the most important, is the admirable summary of the published results obtained up to the time when the Committee commenced work, by Professor W. Cawthorne Unwin, and published in the Proceedings for 1881, pp. 301–368. This paper, along with many valuable suggestions made by its author at the time, formed really the foundation of the whole work of the Committee. The Table compiled by Mr. Ralph H. Tweddell, showing rules of practice used by manufacturers for riveted joints in iron, published in the Proceedings for 1881, pp. 293–299, has proved very instructive. In addition to this, Mr. Tweddell has contributed some remarks on hydraulic riveting to the last Report of the Committee (1885, pp. 228–230); and Mr. W. Silver Hall has added in the same place (pp. 231–235) a collation of Mr. C. H. Moberly's experiments and a few others, with those of the Committee.

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TABLE XXXIV. (*see continuation on opposite page*)

SERIES VIII. *Details of Experiments on Eighteen Single-Riveted Lap-Joints summarised in Table XXIII* (1881, p. 254).

Test Number.	Visible Slip began. Tons.	Total Breaking Load. Tons.	Tearing Area. Sq. Ins.	Tensile Stress per sq. in. Tons.	Shearing Area. Sq. Ins.	Shearing Stress per sq. in. Tons.
652-1	10·6	72·2	2·315	31·21	3·412	21·17
652-2	—	73·7	2·299	32·07	3·430	21·55
652-3	17·7	73·8	2·397	30·80	3·408	21·66
Means	**14·2**	**73·2**		**31·36**		**21·46**
653-1	20·1	72·4	2·308	31·40	4·083	17·74
653-2	12·0	76·1	2·311	32·93	4·064	18·72
653-3	25·1	78·3	2·340	33·48	4·046	19·36
Means	**19·1**	**75·6**		**32·60**		**18·61**
654-1	16·8	68·5	2·231	30·72	3·075	22·29
654-2	13·3	70·4	2·274	30·99	3·100	22·74
654-3	16·1	72·0	2·305	31·25	3·066	23·50
Means	**15·4**	**70·3**		**30·99**		**22·84**
655-1	13·2	75·6	2·666	28·38	3·460	21·87
655-2	16·4	77·2	2·510	30·77	3·482	22·19
655-3	16·9	74·9	2·540	29·48	3·378	22·17
Means	**15·5**	**75·9**		**29·54**		**22·08**
656-1	18·3	69·5	1·986	35·00	3·371	20·62
656-2	18·9	70·1	1·915	36·61	3·371	20·80
656-3	20·1	72·3	1·967	36·77	3·371	21·45
Means	**19·1**	**70·6**		**36·13**		**20·96**
657-1	22·9	74·7	2·472	30·24	3·432	21·78
657-2	18·1	75·2	2·212	34·03	3·442	21·87
657-3	20·9	78·7	2·357	33·41	3·481	22·62
Means	**20·6**	**76·2**		**32·56**		**22·09**

(*see continuation on opposite page*)

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(*continued from opposite page*) **TABLE XXXIV.**

For Dimensions of Joints see Table XXII (1881, p. 253).

(*continued from opposite page*)

Bearing Area. Sq. Ins.	Bearing Pressure per sq. in. Tons.	Efficiency of Joint. Per cent.	Nature of Fracture.
2·196	32·90		Rivets sheared.
2·163	34·09		Do.
2·270	32·52		Do. (one slightly crystalline).
	33·17	**55·1**	
2·400	30·19		Rivets sheared.
2·392	31·82		Do.
2·415	32·45		Plate tore.
	31·49	**54·8**	
2·071	33·10		Rivets sheared (one burnt, head torn off).
2·119	33·25		Do.
2·118	34·02		Do. (ends appeared rather short).
	33·46	**54·9**	
2·222	34·05		Rivets sheared.
2·107	36·67		Do.
2·083	35·96		Do.
	35·56	**54·9**	
2·193	31·70		Rivets sheared {one partly crystalline, and one apparently burnt.
2·105	33·31		Plate tore.
2·171	33·32		Do.
	32·78	**58·6**	
2·013	37·12		Rivets sheared.
1·811	41·56		Do.
1·947	40·44		Do.
	39·71	**60·8**	

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TABLE XXXV.

Summary of Experiments on the Shearing Resistance of different qualities of Steel.

Number of pieces tested.	Shearing Resistance. Tons per sq. inch.	Tensile Resistance. Limit of Elasticity. Tons per sq. inch.	Tensile Resistance. Breaking Load. Tons per sq. inch.	Ratio of Shearing to Tensile Resistance.	Quality of Steel.
2	21·18	16·87	25·55	0·829	Landore Siemens-Steel.
2*	22·75	17·80	28·40	0·800	Do.
3	23·09	16·55	28·45	0·811	Do.
6	24·90	18·11	30·85	0·807	Do.
6	22·71	19·65	31·77	0·715	Weardale Bessemer Steel.
4	28·58	23·00	34·73	0·823	Bessemer Steel.
4	26·27	27·70	36·35	0·721	Do.
2*	33·00	31·00	52·10	0·632	Crucible Steel.
2*	35·20	31·10	52·60	0·670	Bessemer Steel.

In all cases the test piece was formed as sketched in Fig. 10, Plate 29, and was broken in double shear, the double area being taken into account in estimating the resistance per square inch. The diameter of the bar was 1 inch, the turned diameter of the grooves about 0·8 inch, the breadth of the grooves $\frac{1}{8}$ inch, and the distance between them $1\frac{1}{4}$ inch.

* These results are from six experiments made in the writer's laboratory at University College by Messrs. John Platt and R. F. Hayward, and kindly placed by them at his disposal.

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TABLE XXXVI.

Summary of Experiments carried out by Professor Alexander B. W. Kennedy for the Research Committee on Riveted Joints.

The material for the whole of these experiments was provided by the Landore Siemens-Steel Co.

Series.	Detailed Results in Tables	Subject of Experiments.	Specimens prepared by	Specimens tested at	Detailed Results published in Institution Proceedings
I & II	I to VII	Tenacity and Elasticity of Plate, tested both in wedge grips and with pin ends	Mr. W. Boyd	University College, London	1881, p. 206
III	VIII to X	Tenacity and Elasticity of Rivet Steel	Messrs. G. Wailes and Co.	,,	,, p. 213
IV	XI (*see also* XXXV)	Shearing Resistance of Rivet Steel	,,	,,	,, p. 214
V	XII & XIII	Drilled and Punched Plates	Mr. W. Boyd	,,	,, p. 215
VA	XIV & XV	,, ,, ,,	,,	,,	,, p. 216
VI	XVI to XVIII	Single-Riveted Joints	,,	,,	,, p. 219
VII	XIX to XXI	Do. (margin)	,,	,,	,, p. 222
VIII	XXII to XXV (*see also* XXXIV)	Do. in $\frac{3}{8}$-inch plate	,,	Barrow Haematite Steel Works	,, p. 224
IX	XXVI & XXVII	Do. in $\frac{3}{4}$-inch plate	Messrs. John Penn and Sons	University College, London	,, p. 712
X	XXVIII	Do. (high bearing pressure)	Messrs. G. Wailes and Co.	,,	1882, p. 138
XI	XXIX	Double-Riveted Joints, hand-riveted	Messrs. Fielding and Platt	Chain Cable Testing House, Saltney	
XII	to	Double-Riveted Joints, hydraulic-riveted	,,	Chain Cable Testing House, Birkenhead	1885, p. 198
XIII	XXXIII	,, ,, ,, ,,	,,	,,	

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Discussion.

Professor KENNEDY said he had now been able to add the results of about thirty more experiments (Table XXXV) on the shearing resistance of various qualities of steel. These experiments, which had been made subsequently to his report on Series XI, XII, XIII, would be interesting, he thought, as showing that the shearing resistance of steel did not increase nearly so fast as its tensile resistance. With very soft steel, for instance, of only 26 tons tenacity, the shearing resistance was about 80 per cent. of the tensile resistance; whereas with very hard steel of 52 tons tenacity, the shearing resistance was only somewhere about 65 per cent. of the tensile resistance.

Mr. R. CHARLES LONGRIDGE said that probably not many persons could fully realise the trouble entailed in so extensive a series of experiments as Professor Kennedy had conducted. There were one or two points that he should like to allude to, the first of which was the width of the specimens. Possibly for such a material as had been used throughout these experiments—very ductile steel—it might not be a matter of such great importance to have wide specimens, in order to get the mean average strength; yet he could not help thinking that, but for considerations of convenience and cost, it would have been preferred by the author himself to have wider specimens. For in page 218 of the Proceedings of 1881 it was noticed by Professor Kennedy that, "whether owing to the greater number of holes or not, Series VIII gives a greater excess tensile resistance than any of the other joints." Again in the next page a discrepancy in certain results to which the author was there referring was attributed by him to the very small dimensions of the specimens; and it was added (page 220) that "any error in the assumed size of the drilled holes, or any small inequality in the riveting, would of course have an excessive effect on such a very small amount of metal." That was just his own opinion also. It would have been better therefore he thought, though perhaps it would not have been so convenient, to have wider specimens for testing.

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In regard to the shape of the specimens, and the mode in which they were arranged for pulling, he noticed that in all these experiments a central pin had been adopted for holding them in the testing machine. Though he did not know any particular objection to that arrangement, it yet appeared to him rather questionable whether that was as good a plan as the more usual arrangement of several pin holes, adopted by Mr. Kirkaldy and Mr. Moberly. No doubt Professor Kennedy had good reasons for adopting the central pin; but it seemed to him that the other way of holding would have been better.

With regard to the last experiments—Series XI, XII, XIII—he noticed in Figs. 1 to 4, Plate 27, that the ends were narrowed down to the body of the specimens not by means of a curve, but by a straight line making an angle at the junction. In one of Professor Kennedy's previous reports it had been stated that no difference had been found from adopting this form; but for his own part he believed the curve would have been preferable, because he knew that in some cases at any rate the change of section at the junction of two straight lines forming an angle was not a good thing.

In Series X, XII, XIII, all the experiments appeared to have been made upon specimens which had already been tested previously, and were now tested a second time. It might be that the plates had not been injured by the pulling strain to which they had previously been subjected; but having had their strained ends cut off, the fresh pieces re-tested were shorter in each case, and consequently there was a different ratio between the length and breadth of the specimens. It had been mentioned in Mr. Hackney's paper * that the ratio between the length and breadth had some effect upon the results obtained; and he was of opinion that probably it would be so with these specimens, even though the metal itself had not been strained by the previous pulling.

With regard to the last three series in particular—Series XI, XII, XIII—he noticed that the joints were arranged not quite fairly, as he thought, in respect to the amount of the margin, which it was stated had been allowed with the object of equalising the strain.

* Proceedings Institution of Civil Engineers, 1884, vol. lxxvi., p. 70.

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(Mr. R. Charles Longridge.)

It seemed to him that it would be fairer if the width of the specimens tested were made an exact multiple of the pitch. In that case of course some of the rivets would be cut in half; with zigzag riveting that was inevitable. Nevertheless it appeared to him that it would have been fairer, particularly in testing wider joints such as he would have preferred, to have a width equal to an exact multiple of the pitch. The fact of the holes in the specimens tested being arranged in the way they were might account he thought for the high percentage of strength which had been obtained in some of Professor Kennedy's results. These results he believed were nearly 15 or 20 per cent. higher than had been obtained by Mr. Kirkaldy in a series of tests made some years ago for the Bolton Iron and Steel Co. on riveted joints with annealed plates of Bessemer steel; and they certainly appeared to him to show a very high percentage of strength for such joints, even after allowing for the different quality of the material tested in the two cases.

It was to be regretted that hydraulic riveting had not been adopted throughout the whole series of experiments, because the pressure for riveting could be adjusted so much better by the use of hydraulic power. With hand riveting he did not see how it was possible to secure any uniformity of pressure in riveting up. The same man at the end of the day would probably not put so much power into his work as at the beginning of the day. Though not knowing exactly what effect might be produced, he thought some uniformity of pressure would be obtained by using hydraulic riveting machines; and it was especially to be desired that they should be arranged so as to give suitable pressure for the larger rivets, in respect to which it was mentioned that there had been an oversight in Series XII and XIII. In the next series of experiments he hoped some more information would be given as to the different results obtained with different pressures brought to bear on the rivets in riveting up.

Some very interesting particulars had been given by the author with reference to the slip of the joint. He should have been glad if the question of the grip or nip of the rivets had been more gone into, and if some results had been given showing the difference with

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different sized heads, as well as with different pressures brought to bear by the hydraulic riveter. Probably these would be given in the next series of experiments.

In the experiments thus far conducted there was one very interesting point, to which he had alluded (Proceedings 1881, page 267) when the first Report appeared—namely the excess tenacity of perforated steel plates. That excess he believed had been found in almost all the joints and plates tested by Professor Kennedy; but a different result had nearly always been obtained with iron plates, as might be seen in a series of experiments made by Mr. Kirkaldy some years ago upon about nine samples of the very best Yorkshire plates, supposed to be as ductile as iron could be made, in all of which, whether they were drilled or punched, there was a reduction of tenacity in the perforated plates, instead of an excess of tenacity. The difference was of course due to the difference in the quality of the material used; and it was interesting to notice the opposite results in the two materials. Besides those experiments made by Mr. Kirkaldy, he had found the same thing five or six years ago in a very extensive series of experiments with iron plates. In all that series, whether the plates were drilled or punched, annealed or unannealed, instead of there being an excess tenacity with the perforated plates there was a lower tenacity. The discrepancy was no doubt due to the different quality of material used; but it certainly appeared to him somewhat remarkable.

In pages 254–257 of the paper allusion had been made to the maximum strength of joints with double-riveting; but no results had been given of experiments with chain-riveting. In the series of experiments to which he had just referred as having been made five or six years ago, a very decided increase of strength had been found with chain-riveting as compared with zigzag riveting. Simple perforated plates, not riveted, were also tested, and similar results obtained. Iron plates $\frac{1}{2}$ inch thick with holes drilled 3 inches pitch for zigzag riveting did not stand the same stress as pieces of the same plates with holes drilled $2\frac{1}{4}$ inches pitch for chain-riveting. The test plates were so arranged as to have equal sectional area in the two examples. With the zigzag arrangement of holes there

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(Mr. R. Charles Longridge.)

were four pitches in width, or 12 inches total width; and deducting the four $\frac{3}{4}$-inch holes, there was left a net width of 9 inches. For the chain-riveting with $2\frac{1}{4}$ inches pitch there were six holes in each row, making $13\frac{1}{2}$ inches total width, and the holes themselves amounting to $4\frac{1}{2}$ inches left the same net width of 9 inches again; so that the net sectional area was exactly the same. In the case of joints also, chain-riveting showed a considerable increase of strength both in lap-joints and in butt-joints as compared with zigzag riveting; and in practice it had a double advantage for boiler makers. A closer pitch of the rivets could be got with chain-riveting, which of course made caulking better; and there was not that troublesome corner rivet, which in zigzag riveting was sometimes very awkward. Until chain-riveting had been tried, the strongest joint had not been ascertained with certainty. Possibly it might be different with steel*; but certainly in iron there was a great advantage in chain-riveting, both in strength and in simplicity. It was true it made the lap a little wider, because there had to be rather a wider distance between the two rows of rivets in chain-riveting than in zigzag. In continuing these experiments he should be very glad if Professor Kennedy would try chain-riveting, for in the case of iron it was a very decided improvement on zigzag riveting.

On page 258 of the paper the best pitch for 1-inch rivets with $\frac{5}{8}$-inch plates was given as about 2 inches. He thought however it would not be found easy to secure the adoption of such proportions; for it would considerably increase the cost of making a boiler, because it would involve punching a much larger hole at a rather closer pitch than was done in ordinary practice, in Lancashire at any rate.

Professor W. CAWTHORNE UNWIN said that, having had something to do with testing, he was able the better to appreciate the very great labour and the great fidelity with which these most extensive series

* The speaker has subsequently remembered that in Mr. William Boyd's paper on experiments relative to steel boilers (Proceedings 1878, p. 221) it is shown that with steel plates the same pitch of holes gives some 15 per cent. greater strength with chain-riveting than with zigzag.

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of experiments had been carried out by Professor Kennedy. His respect for these experiments would perhaps be most shown by entering into detail and criticising one or two points, in which, while accepting Professor Kennedy's results absolutely, he differed from him in the view that he took of those results.

There was of course a joint of maximum strength; but beyond ascertaining the proportions which in that view were the best absolutely, it was also desirable to see how much a variation from those proportions was likely to affect the strength of the joint. Looking at the matter in that light, he found in Professor Kennedy's tables a result at which he confessed he was surprised. The largest single consecutive series of experiments was Series VIII, in which eighteen very large joints had been tested at Barrow. They were not intended to be all good joints. Some of them were made to have an excess of tearing area, some an excess of shearing area, and so on. The ratio of rivet diameter to thickness of plate varied 21 per cent. (Table XXII), the ratio of shearing to tearing area varied 30 per cent., and the ratio of crushing to tearing area varied 34 per cent.; so that every possible proportion of the joints had been varied to an extent of from 21 to 34 per cent. Looking at the efficiency of the joints (Table XXIII), it would be found that the efficiency of the weakest joint was only 6 per cent. less than that of the strongest. In other words, while the proportions had been varied from 20 to 30 per cent., the efficiency had varied only 6 per cent.; or, to put it a little more fairly, the whole variation of strength was only 11 per cent. of the strength of the weakest joint. Individual results might no doubt be obtained which would differ very much more from the mean; but he thought it was a rather striking fact that in the largest of the complete series of experiments there should be only that amount of variation in strength.

Allusion had been made at the close of the present paper to the provisional report which had been prepared by himself for the Research Committee in 1879, and had been printed in the Proceedings of 1881 (page 301). Looking through Professor Kennedy's last report, he was glad to say he did not see that he had been very far wrong in the conclusions which had been drawn by himself in that first report.

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(Professor W. C. Unwin.)

One or two of Professor Kennedy's conclusions he desired to touch upon. In the first place, Professor Kennedy had pointed out (page 249) the increase of tensile strength per square inch in a perforated plate as compared with the unperforated metal. In his own provisional report (1881, p. 319) he had pointed out, not perhaps for the first time, but at all events he had drawn pointed attention for the first time to the fact, that in certain cases there was an increase of strength in the perforated plate as compared with the unperforated plate. When commenting upon Professor Kennedy's first report which was read in April 1881 (p. 205), he had attributed that result (p. 284) to the contraction of area being hindered by the neighbourhood of less strained material behind the section of fracture; and he still adhered to that view. On this point he had now a little additional evidence which he should like to give. In pulling asunder a very short test-bar, the tensile strain was greater at the fracture than it was at a little distance before or behind; and the lower strain on the material at a little distance from the most strained section diminished the contraction of area. In the report of the United States Testing Board he observed that a series of iron test specimens had been prepared of the ordinary form, turned down to a smaller diameter for a certain portion of their length; and the length of this turned part being gradually reduced, it was found that the strength began to increase when the turned length was less than one diameter. The strength was indeed thought to be already increased as soon as the turned length was less than three diameters; but it was decidedly increased when the turned length was less than one diameter. When the turned length was still further reduced, so as to be little more than a mere groove round the test specimen, the contraction of area was so far diminished that the strength increased 30 per cent. in the most ductile iron. In similar grooved test bars of a more rigid quality of iron the strength was increased only 5 per cent. Thus in the iron which had little contraction of area the strength was little increased by diminishing the contraction; in the iron which had great contraction of area the strength was greatly increased when the contraction was diminished. A still more striking instance was furnished by two specimens of Whitworth

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compressed steel which Mr. Hawksley had been good enough to send him the other day. One of them he had turned to the usual form, the turned length being several diameters long; and the other he had notched out to exactly the angle and form of a Whitworth screw thread. The specimen with the long turned portion broke at 36 tons per square inch of original area, and the notched specimen at 53 tons, being an increase of 47 per cent. The contraction of area in the former was 54 per cent., and in the notched specimen it was nothing. This he thought was evidence at all events that the hindering of the contraction of area had to do with the increase of strength.

With reference to the effect which the crushing pressure on the rivet produced upon the strength of the joint, there were some old experiments, especially those made by the late secretary of the Institution, which showed that, when the bearing pressure on the rivet became very large, there was a great diminution in the apparent tenacity of the plate in the case of riveted joints in iron. On examining steel joints he had mentioned in the report (1881, page 330; see also page 285) that there was no evidence that the tenacity of the plate was affected by a high crushing pressure on the rivet, even when it amounted to 40 or 50 tons per square inch. A slight indication he had found, and had mentioned it (1881, page 334) that in the case of steel, while the tenacity of the plate was not affected, the shearing resistance of the rivet was. He had pointed out that it appeared in some cases the rivet was harder than the plate, and the plate was injured, and in other cases the rivet was softer than the plate, and the rivet was injured; and the latter appeared to be the case with steel joints. That was entirely confirmed by Professor Kennedy's experiments, because these had shown that the crushing pressure had no influence on the tenacity of the plate, and that it had an influence on the shearing resistance of the rivet (1885, page 251, conclusion v). Now at this point there was still a difference, he thought, between Professor Kennedy and himself. Why was it that the crushing pressure should affect either the tenacity of the plate or the shearing resistance of the rivet? He believed that it did not really affect either. What happened was that, if the

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(Professor W. C. Unwin.)

crushing pressure exceeded a certain limit, there was a flow of the metal, and the section which was resisting the load was diminished. Either the section of the plate in front of the rivet if the plate was soft, or the section of the rivet itself if the rivet was soft, became reduced, and at last became so small that it gave way to the tearing or to the crushing force. What really happened therefore on exceeding a certain limit of crushing pressure was, not that the real tenacity of the plate or the real shearing resistance of the rivet was diminished, but that a flow of metal was produced which diminished the resisting section of the metal.

In the provisional report (1881, p. 366) he had suggested that a line should be scribed across the edges of the joint, in order that the point at which visible slipping occurred might be observed. In the later experiments made by Professor Kennedy he was glad to see that it had at last been found, by observations of this kind, that hydraulic-riveted joints were much better than hand-riveted joints. But the exact bearing of this result he thought was not rightly stated in Professor Kennedy's paper. In all Professor Kennedy's reports except the last, the load at which slipping occurred had been recorded as the load per square inch of sectional area of the plate; but he did not think the point at which slipping occurred had anything more to do with the tension in the plate than with the length of the lever of the testing machine. If the load were calculated not upon the sectional area of the plate, but upon that of the rivets, he believed the results would be more significant.* In one or two instances in which he had worked out the figures in this way, he thought more significance was obtained by this mode of reduction. In one case for instance (1881, p. 716) it was stated that the greatest load at which visible slipping first occurred was 6 tons per square inch of tension in the plate; and in the joint where the slipping occurred earliest it occurred at 3·6 tons per square inch. Three joints were given, Nos. 1234, 1235, and 1236: in Nos. 1235 and 1236 slipping occurred at 6 tons tension; and

* The frictional resistance to slipping depends on the sectional area of the rivets, but of course it also varies with the pressure used in riveting, the temperature of the rivet at the moment of closing, &c.

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in No. 1234 at 3·6 tons tension; and those figures were very discrepant. But looking at Table XXVI (1881, pp. 717–718) and working out from it what the load per square inch of rivet area would be, the figures were quite simple: they came out at 3·5, 3·2, and 3·4 tons per square inch of rivet section. These figures were quite accordant; and moreover they were very nearly the figures long ago found by Mr. Edwin Clark to be the frictional resistance of the plates to slipping, in joints in which there could be no shearing, because the rivet holes had been purposely made elliptical. In hand-riveted joints at all events he was persuaded that the point at which visible slipping occurred meant the point at which the initial friction of the plates was first overcome; it had nothing to do either with tension of the plates or with shearing resistance of the rivets. Consequently if greater pressure was put on the rivets in riveting up, as was done by hydraulic riveting, there was a greater grip upon the plates and greater friction between them; and then loads were got as high as 10 tons per square inch of rivet section before slipping occurred. It would not do to interpret too rigidly. The thing in regard to visible slipping was that it indicated mainly the initial point at which the friction between the plates was overcome. In a rather loosely riveted joint, the rivet fitted the hole so imperfectly that he believed the entire resistance to slipping was due to friction; whereas in joints very closely riveted up, the shear of the rivet might a little help the resistance to the beginning of slip. But in the main he thought that it would be right to regard the point at which visible slip commenced as the initial point at which the friction of the plates was first overcome.

In regard to the rules given by Professor Kennedy for designing lap and butt joints, he thought it would have been a little more accurate if these joints had been described as single-shear and double-shear joints, because there were many butt joints in which the rivets were in single shear, and these would have to be designed by the rules given in the paper for lap joints; it was only to double-shear joints that the rules now given for butt joints would apply. These rules at first sight looked extremely different. Equating the

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(Professor W. C. Unwin.)

load on a joint to the tearing resistance of the plates, one equation was obtained; equating it to the shearing resistance of the rivets, a second equation was obtained; and equating it to the crushing resistance, there was a third equation: so that there were three equations for determining the proportions of the joints, and these three equations determined the thickness of the plates and the pitch and diameter of the rivets, the tensile and shearing and crushing resistances being assumed as given by experiment. A joint designed by those three equations would be what might be called a theoretical joint; and it would be found that, taking the crushing resistance as double the tenacity—which was a figure selected by himself some years ago (in "Machine Design" 1877 and 1882) and was very little different from Professor Kennedy's figures—the following relations between the diameter d of the rivets and the thickness t of the plates would be arrived at: in all single-shear joints such as lap joints $d = 2 \cdot 57\, t$, and in all double-shear joints $d = 1 \cdot 27\, t$; that is, the diameter of the rivets must be two and a half times the thickness of the plates in a single-shear joint, and one and a quarter times in a double-shear joint. In a single-shear joint the rivet could not in general be made so big, and the rivet diameter was accordingly chosen arbitrarily; but having chosen the rivet diameter arbitrarily, it was not possible to satisfy all the three equations, and the joint had then to be proportioned by the two equations for shearing and tearing. In double-shear joints on the other hand the rivet could not always be made so small as only one and a quarter times the thickness of the plates, and it was therefore necessary to proportion for crushing and tearing. Thus in the single-shear joints no attention was paid to the crushing resistance, and in the double-shear joints no attention was paid to the shearing. This conclusion was identical with Professor Kennedy's, differing only in the way in which it was put. The general drift of Professor Kennedy's report was no doubt to urge the adoption of a larger diameter of rivet than had been usual in practice. Whether this could be done or not, he was not prepared to say. For lap joints the adoption of a larger diameter would no doubt increase the strength of the joint, though the increase would be less for double-

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riveted joints than for single-riveted. On the other hand he was not sure that for double-shear joints it would not be better to diminish the size of the rivet; at all events by diminishing the size of the rivet the crushing pressure would be brought down within the limit which was permissible.

In thus criticising Professor Kennedy's paper he was quite sure it would not be thought that he did not set the very highest value on the great amount of work which had been accomplished by the author.

Mr. P. D. BENNETT considered it was impossible to exaggerate the importance of the experiments conducted by Professor Kennedy; and he was sure the members were all very deeply indebted to him for the results he had so far given. They must however wait for the completion of his experiments before forming a definite opinion with respect to them. In regard to the mode of holding the specimens in the testing machine, he could not help thinking that Professor Kennedy was right theoretically in having a central pin in the ends of the test piece, because a direct central pull through the test piece was thereby secured with more certainty than could be the case with clip clutches; while on the other hand, if there were several pin holes in each end, it was very difficult to conduct a series of experiments, owing to the time occupied in fixing and removing the specimens. As to the width of the specimens and the proportioning of the joints, though he had not followed all the results given in Professor Kennedy's reports, he thought the author was right in the views that he took.

At present he was himself engaged in experiments as to the difference between the effect of a punched hole and a drilled hole in test pieces, and also the difference after a punched hole had been drilled. When these experiments were completed he should be happy to give the results to the Institution. The drilling of the holes he thought must now be accepted as the best method of doing the work. At the same time his present opinion was that, if the holes were punched so much smaller as to leave from one-sixteenth to one-eighth of an inch to drill out all round, the strength of the

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(Mr. P. D. Bennett.)
plate would be as great as though the holes had been drilled out of the solid; and he should be prepared after a time to state positively how far this conclusion was confirmed by actual experiment.

With regard to hydraulic riveting or steam riveting, all that was wanted in either method was to put the same pressure on the heads of the rivets throughout the whole series of experiments; and whether this was done with the hydraulic riveter or with the steam riveter, the effect would of course be the same. He fully concurred in the great importance of having the heads of the rivets sufficiently large, as pointed out by Professor Kennedy, so as to nip the plates together and get that friction between them, the value of which had been urged by Professor Unwin; and he agreed with him as to the initial slip of the plates, that it began the very moment the friction caused by the nip of the rivets was overcome.

Mr. C. H. MOBERLY said he felt in common with all the members of the Institution very grateful to Professor Kennedy for the very elaborate and extensive series of experiments he had made. While these were going on, he had himself had to make some steel boilers; and not being able to wait for Professor Kennedy's results, he had had some test specimens prepared of Landore Siemens-steel, and had instituted a set of experiments simply for his own guidance, first of all with 9-16ths inch plates, then with 7-16ths inch, and lastly with 5-16ths inch plates; and he had tabulated the results for use in making boilers, pending the result of Professor Kennedy's investigations.

As the standard breaking tensile strength for the steel, he had adopted 30 tons per square inch, with 20 per cent. extension in a length of 10 inches. Some years ago, very properly he thought for those times, the Admiralty, Lloyd's, and the Board of Trade had adopted for the tensile strength of steel plates the limits of from 26 to 30 tons. At the present day he saw no reason why 30 tons should not be adopted, or say from 29 to 31 tons, the fact being that plates of that strength had been used in Professor Kennedy's experiments; and he thought if all boiler-makers and engineers would insist on that standard they would get it without

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extra price. They would then be able to advance a little further in the application of such admirable material as mild steel. His own experiments had all been made with punched plates not annealed; and therefore the resulting strength of the steel in the joints was not the same as in Professor Kennedy's joints with drilled holes. From his own limited experiments, as the result of actual trial in the joints, he had adopted roughly the following scale for the ultimate tensile strength of the net metal between the rivet holes along the straight line of rivets :—

Thickness of Plate, inch	$\frac{3}{16}$ & $\frac{1}{4}$	$\frac{5}{16}$ & $\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$
Ultimate Tensile Strength of plate between rivets, in tons per square inch	32	31	30	29	28	27

The next thing to be considered in a good steel joint was the rivets; and here a very troublesome question was met with, on account of the rivet steel varying so greatly. When first riveting steel boilers with steel rivets some years ago, he had been very much annoyed to find that the heads came off; it was found however that the rivet steel had in error been supplied of too hard a quality, having a tensile strength of 50 tons per square inch, which of course rendered it useless for rivets. Since that time he had succeeded much better, and as a matter of fact had obtained in the joints a shearing strength amounting to 85 per cent. of the tensile strength of the rivet steel: the tensile strength being 30 tons per square inch, the shearing strength was as much as 25 tons per square inch as the result of actual trial, with punched holes in double-riveted joints; in single-riveted joints it was only 23 tons per square inch.

It was not sufficient however to have steel rivets with that shearing strength; it must also be ascertained that they were properly put in. What was wanted of a rivet was that it should fill the hole, not when it was hot, but when it was cold. Ordinarily rivets were put in pretty hot, iron rivets especially at a very bright heat; they then cooled, and the argument was that they would nip or grip the plates together. That was all very well, but in doing so they also contracted laterally; and when the rivets were cold they did not fill the holes perfectly. That was less the case with steel

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(Mr. C. H. Moberly.)

rivets, because steel rivets ought to be worked much cooler, at a dull red heat probably. He had commenced riveting steel rivets at a tolerably bright heat, and several years ago had arranged the following scale for the total pressures to be put upon the rivets in lap and butt joints with different sizes of rivets and thicknesses of plates:—

Lap Joints.

Thickness of Plates, inch.....	$\frac{9}{16}$ & $\frac{1}{2}$	$\frac{1}{2}$ & $\frac{7}{16}$	$\frac{7}{16}$ & $\frac{3}{8}$	$\frac{3}{8}$ & $\frac{5}{16}$	$\frac{5}{16}$ & $\frac{1}{4}$
Diameter of Rivets, inch	$1\frac{1}{8}$ & $1\frac{1}{16}$	1 & $\frac{15}{16}$	$\frac{7}{8}$ & $\frac{13}{16}$	$\frac{3}{4}$ & $\frac{11}{16}$	$\frac{5}{8}$ & $\frac{9}{16}$
Total Pressure on Rivet, tons	35	30	25	20	15

Butt Joints with Double Covers.

Thickness of Plates, inch.....	$\frac{9}{16}$	$\frac{1}{2}$	$\frac{7}{16}$	$\frac{3}{8}$
Diameter of Rivets, inch.....	$\frac{13}{16}$	$\frac{3}{4}$	$\frac{11}{16}$	$\frac{5}{8}$
Total Pressure on Rivet, tons	35	30	25	20

He had not had occasion to use all these pressures and combinations; but as far as he had used them they had given good results, the respective pressures being sufficient for the rivets when heated to a tolerably bright red. More recently however the heat at which the rivets were worked had been greatly reduced; and they were now put in at a very dull red heat, with the result he believed of filling the holes much better and making a better joint. The pressures used for the colder rivets were from 5 to 10 tons higher than those above given. To get the most perfect joint, he considered the holes should be drilled, and the rivets turned and riveted cold. In this matter he spoke from experience, because some years ago he had had great difficulty in making a particular joint tight; it could not be got tight until at last he had the holes rimered out and turned rivets put in and riveted cold, after which there was not a leak in it. Therefore the nearer that state of things could be approached, the more perfect he believed would the joint be. If the heat of the rivet could only be kept down to a dull red, the joint would do very well. Unfortunately in none of Professor Kennedy's experiments had the pressure been given with which the rivets had been put in; and differences in the pressure he thought would to some extent account for some discrepancies. Certainly it would be a very great

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advantage if in all future experiments a record could be given of the actual pressures on the rivets.

What had been said by Professor Unwin about slipping coincided exactly with his own view:—namely that slipping commenced at so low a pressure, simply through the friction being overcome, and in consequence of the rivets not completely filling their holes. If the rivet holes were perfectly filled, the plates could not slip without at the same time to a certain extent shearing or crushing the material. That was another reason for filling the holes as well as could be. Then as to the rivet heads, he believed these had often been made too small, as proved by Professor Kennedy's experiments. Hand-riveting had proved inferior to hydraulic riveting for the same reason, he thought, namely that the rivet could not be made to fill the hole; it never did so in hand-riveting. All engineers knew what it was to have a boiler tested and the rivet-heads leaking, so that it was necessary to caulk them all round. That ought not to be: if the rivet filled the hole, it would not leak.

As to the proportion of the joints in double-riveting, it had been found by Professor Kennedy that the straight pitch should exceed the diagonal pitch by about 30 per cent. In going through his own experiments, he had tried to account for the difference in the strength of the material when breaking straight across and when breaking diagonally; and had been strongly impressed by the fact that in one or two cases the diagonal fracture had taken place not really diagonally, but one portion of the fracture had been along the straight line of the row of rivets, and the other portion nearly at right angles to it: which in his opinion pointed clearly to the fact that part of the metal was sheared and part was torn. As the result of different trials, he had found that as nearly as possible the strength along the diagonal line was arrived at by assuming that the metal along that line was subjected to both a tensile and a shearing stress; and that one part of the pull applied had to overcome the tensile strength, and the other part the shearing strength; and yet further, that the metal, being exposed to both stresses simultaneously, offered only half the resistance to each of the two when combined which it would to each separately. Then putting d = diameter of

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(Mr. C. H. Moberly.)

holes, t = thickness of plates, p = straight pitch, l = net width of plate between adjacent rivets in straight row = $p-d$, m = distance between centre lines of the two rows of rivets, s = tensile strength per square inch, and taking the shearing strength as 85 per cent. of the tensile:—the tensile strength along l would be $s\ l\ t$, the shearing strength along m would be $0{\cdot}85\ s\ m\ t$, and on his assumption the strength along the diagonal line would be $\frac{1}{2}\ (s\frac{l-d}{2}\ t + 0{\cdot}85\ s\ m\ t)$, which must be equal to $\frac{1}{2}\ s\ l\ t$; whence $\frac{1}{2}\ (l-d) + 0{\cdot}85\ m = l$, and therefore $m = 0{\cdot}59\ (l+d) = 0{\cdot}59\ p$; that is, the distance between the centre lines of the two rows of rivets must be 59 per cent. of the straight pitch. This made the diagonal pitch = $\sqrt{(\frac{1}{2}p)^2 + m^2} = 77$ per cent. of the straight pitch. This result coincided remarkably with that of Professor Kennedy, who had found (p. 251) that the net metal measured zigzag should be from 30 to 35 per cent. in excess of that measured straight across, and had consequently given $\frac{2}{3}p + \frac{1}{3}d$ as the proper amount for the diagonal pitch. For if the straight pitch were equal to three or to four times the diameter of the holes, this expression would make the diagonal pitch equal to 78 or to 75 per cent. respectively of the straight pitch, being a close approximation to the relation above deduced from his own method of viewing the matter.

In regard to the margin, he had found there were so few data to go upon, that he had not been able to arrive at a definite conclusion; and he had simply adopted the rule that the margin should be 56 per cent. of the metal from rivet to rivet. But he thought that more information was wanted on this point, as he was not aware of any experiments having been tried to determine it.

As to the straight pitch, that was of course a practical matter. The theoretical joint mentioned by Professor Unwin would, as he had himself remarked in mentioning it, be quite impracticable. What had to be done in practice was to determine the greatest pitch that could be used in any particular plate. From practice and experience he had found that with $\frac{3}{8}$-inch iron plates and $\frac{3}{4}$-inch iron rivets a pitch of $2\frac{1}{4}$ inches in single-riveting made good tight boiler-work; that left $1\frac{3}{8}$ inch width of net metal between the rivet holes. For steel he assumed 25 per cent. more was admissible

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for the net metal between the holes, or say $1\frac{11}{16}$ inch, which was $4\frac{1}{2}$ times the thickness of the plate; and he had adopted this as a maximum limit for single-riveting. The pitch would then be equal to $4\frac{1}{2}$ times the thickness of plate, *plus* the diameter of the rivet hole. But as that pitch would require too large rivets, he had adopted generally for single-riveting a pitch equal to six times the thickness of plate, which worked out very well and made tight work. The next question was how much wider could the pitch be in double-riveting zigzag. There were no data with regard to caulking, which was what fixed the practical limit; the pitch must not be increased beyond what could be caulked. Again assuming therefore that in double-riveting 25 per cent. might be added to the previous net width of metal between the holes in single-riveting, that width would become $5\frac{5}{8}$ times the thickness of plate; and he had accordingly adopted a pitch equal to eight thicknesses of plate, which gave perfectly satisfactory results up to a steam pressure of 80 lbs. per square inch; he had no experience with higher pressures.

One example of the application of these rules was a boiler of 6 feet diameter, made of $\frac{5}{16}$-inch Landore Siemens-steel plates, having double-riveted lap-joints with punched holes, and $\frac{5}{8}$-inch rivets at $2\frac{1}{2}$ inches pitch; lap $3\frac{1}{2}$ inches, distance between rows of rivets $1\frac{7}{16}$ inch, hydraulic pressure on rivets 20 tons, working steam-pressure 75 lbs. per square inch. The joint was calculated for 74 per cent. efficiency; and that was about the actual efficiency realised in tests of specimen joints so made. Another instance was a boiler 9 feet diameter, of $\frac{7}{16}$-inch Landore Siemens-steel plates, with double-riveted lap-joints and $\frac{7}{8}$-inch rivets; holes punched $\frac{3}{4}$ inch and rimered out to $\frac{15}{16}$ inch, pitch $3\frac{1}{2}$ inches, lap $4\frac{1}{2}$ inches, distance between rows of rivets $1\frac{7}{8}$ inch, hydraulic pressure on rivets 35 tons, working steam-pressure 80 lbs. per square inch. The actual strength in testing sample joints again coincided with the calculated strength, namely 72 per cent. of that of the solid plate. Both of these boilers had proved quite tight and satisfactory in actual work.

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Mr. JOHN ROBINSON said the danger had to be guarded against of mixing up results obtained from different qualities of plates, in dealing with the practical question as to how the greatest strength was to be got in making boilers. It had been asked lately, since the question of the application of steel for the manufacture of boilers had been discussed, what was steel and what was iron? and the answer had been given that some of the mild steel, such as that which Professor Kennedy had been experimenting upon, was only pure iron. Now one very remarkable fact that greatly affected the construction of boilers was the marvellous difference that had been shown in the behaviour of real steel, such as Landore Siemens-steel, and of iron, such as that upon which Mr. Longridge had experimented. In the one case there was a surprising increase of strength after perforation, and in the other case there was a diminution of strength. In reading Professor Kennedy's present paper he had noted in page 238 the mention made of the plates being punched and drilled; and he agreed with Mr. Bennett that the question whether they were punched or drilled was a very important one. A further disturbance of the conditions had now been introduced by Mr. Moberly's quotation of experiments, in some of which steel plates had been punched only, without any drilling after the punching. Evidently therefore it was almost impossible to get at any satisfactory conclusion, unless these several conditions were kept very clearly distinct. In a recent discussion at the Institution of Civil Engineers upon the construction of boilers, one of the speakers had still advocated the old hand-riveting with iron plates; but he himself thought the present tendency was all in the direction of steel plates, and steel rivets for fastening them together; and this tendency he considered was fully justified by the results which Professor Kennedy had now brought before them.

Steel makers would not in his opinion be quite fairly dealt with, if called upon for a higher effective tensile resistance than for some time past had been asked for in the manufacture of boilers; for a steel of greater tenacity must be what was called a harder steel, which must have a larger proportion of carbon in it; and with a larger percentage of carbon there was a danger on some occasions,

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when subjected to certain strains, of fracture taking place before elongation had gone on to the same extent that it would have done with a softer steel. An instance of that kind had been given by Mr. Moberly himself, in his mention of the steel rivets with which he had found fault. On the one hand he had said the steel ought to have a higher tensile resistance, which more carbon in the steel would no doubt give; whereas on the other hand it would appear that for steel rivets a softer steel was necessary, because when he had happened to get a hard steel, which was not intended for rivets, the action of the hammer upon the head of the rivet—whether it was riveted by hydraulic power or by the ordinary riveting hammer—tended of course to crystallise the head still more, and the head came off. A similar result he feared would follow if, in order to obtain the higher tensile strength desired by Mr. Moberly, steel plates were used containing too large a proportion of carbon. Such steel might be desirable for some purposes, but not for steam boilers, which above all things required plates of constant quality.

The experiments which Mr. Bennett was making would he thought be very useful. But he should like if possible to get at the bottom of the very important question about increased tenacity in mild steel plates when perforated, as compared with the unperforated plates; and on the other hand to account for the well-known diminished tenacity in iron plates when perforated, especially if punched. For until the cause of this difference was fully cleared up, there must continue to be some hesitation about accepting the equations which gave the pitch, the diameter, and the margin. Evidently there was some much greater distinction between the behaviour of iron and the behaviour of mild steel than many engineers had hitherto supposed; and he for one was exceedingly obliged to Professor Kennedy for giving prominence to these results, because, unless it were known where the weak points were, remedies could not be found for them by iron and steel manufacturers.

With regard to hydraulic riveting, there was a very remarkable statement in page 247 that the hydraulic-riveted joints had not been found to any extent more satisfactory than the similar hand-riveted joints; and it occurred to him whether that result might not have

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(Mr. John Robinson.)
arisen from the rivet-heads having possibly been smaller when hydraulic-riveting was used than when hand-riveting was used. In one instance (page 243) it was stated that the joints had been riveted over again with heavier rivets; and by heavier rivets he understood from page 250, not rivets of larger diameter, but longer rivets, forming larger heads when they had been riveted up, and therefore giving greater gripping power on the plates, because the larger heads would not so readily yield under the stress either in experiments or in practical use. He quite concurred in Mr. Moberly's remark as to the necessity of always recording the pressure under which the rivets were put in by hydraulic power, because upon that depended much their effective grip upon the plates. If the plates could be held so tight by the gripping power of the rivets as never to move at all, he thought the efficiency of the joint would then be not 80 per cent. but probably 90 per cent. of the strength of the solid plate. As soon as the plate began to move, there must naturally be some mischief beginning; not only was there leakage from the boiler, but the joint was so to speak un-making itself, and was illustrating the proverb that a stitch in time saved nine; for if the first stitch were not looked after when it gave way, the rest of the joint was likely very soon to follow. It was exceedingly important therefore to have plenty of material in the heads of the rivets, in order to give the grip necessary for preventing the first beginning of slip. The vital difference between hand-riveting and machine-riveting in regard to slipping had been clearly brought out in page 248, where it was stated that in hand-riveted joints slipping began at an average absolute load of 26 tons, and in hydraulic-riveting at 51 tons. This difference constituted in his opinion a sufficient justification for riveting either by hydraulic or by steam power.

The two things therefore to be borne in mind were, first of all the great advantage of grip, which was given by the use of hydraulic or steam riveting; and secondly the right quality of the material employed, because upon that material, whether steel or iron, must depend the mode of manipulation, whether by drilling or by punching, or partly punching and partly drilling. These were the

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great questions for boiler makers; because, as had been said by Professor Unwin and also to some extent by Professor Kennedy, the question of pitch, diameter, and margin depended often upon reasons which were outside the theoretical investigation altogether.

Mr. Druitt Halpin recommended that, when punching and drilling were compared, care should always be taken that the punched plates should be tested exactly as they left the punching machine; that is, they should be put together with drifts and without riveting, and be so tested in the testing machine. For if a punched joint was riveted up, a very distinct difference took place, owing to the annealing which must go on. The bodies and the heads of the rivets formed a considerable proportion of the joints; and if the rivets were put in at anything like high temperature, a more or less perfect annealing would take place; and it was well known that the original strength of the plate could be reproduced by sufficient annealing. This consideration might account to some extent for the discrepancies which had sometimes been found in comparisons between drilled and punched plates.

One of the most valuable facts brought out in Professor Kennedy's paper was the slipping, which he had never seen noticed so clearly before, although Professor Unwin had alluded to Mr. Edwin Clark's experiments on that point. The earliest point given in page 248 as that at which the slipping was found to begin in hand-riveted joints was when the load had reached only 16 per cent. of the strain of rupture. As boilers were often worked in practice at one-sixth of the strain of rupture, they must really be working at the slipping strain; and the commencement of slipping had already been spoken of as practically coinciding with the commencement of leakage. But here also the conditions in actual work in the boiler were different from those in the testing machine. In the machine all the tests were made cold, or at some very low temperature; whereas in the boiler the temperatures ranged up to 350° F. That difference might account for leakage taking place, as it would do in large marine boilers, at the bottom, and not at the top, especially while the steam was being got up; because temperatures and pressures had no relation whatever to

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(Mr. Druitt Halpin.)
each other in those boilers while the steam was being got up. At the top their joints had temperatures corresponding with their pressures, and were tight; at the bottom the joints were relatively cold, and slipping and consequent leakage might take place.

Professor KENNEDY said that, although this paper had been treated as his own and had been prepared by himself, it represented not only his own work but the work also of a good many committee meetings in which other members of the Institution besides himself had been concerned. He was glad that it had elicited a discussion in which the subject had been dealt with both from a practical and from a scientific point of view.

The points mentioned by Mr. Longridge were many of them points that must be, to a greater or less extent, matters of opinion. Although in test-pieces for tension the rounding out of the corners was essential, yet when the corners themselves were 8 or 9 inches away from the only part of the joint which could break, he really did not think it worth while to go to the extra expense of machining them round in order to get rid of the present very obtuse angles.

Whether the re-tests of the old joints were as good as new experiments was of course an important question, upon which every one must form his own opinion. Most results had shown that a re-tested piece of metal was generally stronger than before; but it had to be remembered that the unstrained metal in the joints, which formed the riveted part of the plate in the re-tests, had not been strained beyond the limit of elasticity; and there was no reason for supposing that material which had not been stretched beyond the limit of elasticity had had its breaking strength affected. And there was of course a great convenience in testing a second time metal of which everything else was already known, its tensile resistance and all its other behaviour having previously been accurately noted.

As to the shape of the fastening for holding the specimens in the testing machine, he thought on the whole the pin fastening, made in the way shown in Figs. 1 to 4, Plate 27, was probably the one that distributed the load best; and it was certainly one that enabled the

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specimens to be handled in and out of the machine in a small fraction of the time required to loose the nuts of a dozen pins. At any rate there was no reason to doubt in any of these experiments that the stress had been very uniformly distributed by the thickened-up ends put together with so large a number of rivets. There was no doubt that the excess tenacity of perforated plate was a characteristic of steel and not of iron. This was shown, for instance, by Mr. Kirkaldy's experiments for Mr. Traill. It was strange to find so great a difference in materials so nearly alike. Its only probable cause seemed to lie in the difference of structure due to the original difference between the homogeneous ingot and the piled bloom. He was much obliged to Mr. Longridge for raising these and other points, which certainly ought to be ventilated; and would bear in mind his suggestion about chain-riveting in future experiments.

With regard to the contraction of area at the point of fracture in a bar pulled asunder in tension, two pieces of compressed steel had been instanced by Professor Unwin, one of which broke at 36 and the other at 53 tons per square inch. The latter, having been grooved with so short a neck, no doubt did really break at the 53 tons; that is, 53 tons per square inch was the maximum load when it broke. But the other probably broke at a much higher stress per square inch of actual area at the instant of fracture than the breaking load divided over the original area, which he understood 36 tons per square inch to be; at least that would be the case in most instances. He was quite prepared to believe that the support given by the metal behind the narrow portion that broke had a very great influence on the strength of the piece. But if that were the only cause of the additional strength, it would follow that a flat bar 3 inches wide, with an inch hole drilled through its centre so as to leave 1 inch of metal on each side, ought to have the same strength as a second bar of the same width notched out on each side with a semicircle of 1 inch diameter so as to leave 2 inches breadth of metal between; because the curved outline was the same shape in each, and each had an equal amount of metal behind the place of fracture, tending to support them equally. Yet in every case in which he had experimented on that point, although he had not made a very large

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(Professor Kennedy.)

number of experiments upon it, he had found that the piece notched out on each side stood a heavier load than the piece with the central hole; and he was inclined to believe that the difference was due to the cause which he had originally mentioned (1881, pp. 217–218). He quite admitted that the explanation he had then given did not account for the whole excess of strength in a perforated plate; but still he thought it accounted for a certain proportion of it, though he could not say how much.

In speaking originally of the slip of a joint in terms of the tensile resistance, he had been doing, to begin with, what seemed natural, because the tensile resistance was what was spoken of from the outset, and formed a kind of measure for the working of a joint. But it had soon become clear that slip and tensile resistance had nothing to do with each other; and perhaps it would therefore have been wiser to cease speaking of slip in terms of tensile resistance, although he hardly thought there could be any practical misunderstanding on the point. As stated in the paper (page 252) he himself thought the slip depended upon the number and size of the rivets in the joint; and apparently it depended also on the type of joint. This view practically came to very much the same as that taken by Professor Unwin.

As to the pressures put upon the rivets in the hydraulic riveting, about which Mr. Moberly had enquired, he was told by Mr. Tweddell (whose unavoidable absence that evening he regretted) that the pressure used in riveting up the joints had in all cases been about 35 tons per square inch, both for the 1·1 inch and for the 0·7 inch rivets. There appeared unfortunately to have been only one machine available for riveting them up at first. Mr. Tweddell thought that this pressure had been too great for the smaller joints, having "spread out" some of the plates a little; and too small for the larger joints. He was further informed by Mr. Tweddell that the time during which the hydraulic pressure had been maintained on the rivet head had also varied, and that the following observations had been noted in Series XII:—

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Test No.	Joint.	Rivet holes.	Duration.
1480–1	$\frac{3}{8}$-inch lap	0·8 inch diam., pressure on rivet head	15 seconds.
1484–1	„ butt	0·7 „ „	2 „
1486–1	$\frac{3}{4}$-inch lap	1·1 „ „	20 „
1490–1	„ butt	1·1 „ „	15 „

In the new experiments now in hand the pressures would be varied throughout in accordance with Mr. Tweddell's experience.

In regard to the question asked by Mr. Robinson, he could not speak as to the size of the rivet heads, but was informed by Messrs. Fielding and Platt that the lengths of the rivets used had been as follows:—

Joint.	Rivet holes.	Series XI.	Series XII.
$\frac{3}{8}$-inch lap	0·8 inch diameter, length of rivets	$1\frac{7}{8}$ inch	$1\frac{7}{8}$ inch
„ butt	0·7 „ „	2 „	$2\frac{1}{8}$ „
$\frac{3}{4}$-inch lap	1·1 „ „	$2\frac{3}{4}$ „	$2\frac{5}{8}$ „
„ butt	1·1 „ „	$3\frac{1}{4}$ „	$2\frac{7}{8}$ „

The lengths here given first were those for Series XI, and the lengths given second for Series XII. He had not got the information for Series XIII; nor was he able to account for the difference in length, which he had not known of at the time.

Mr. P. D. Bennett asked whether the holes were drilled or punched in the experiments on perforated plates, as well as in those on riveted joints.

Professor Kennedy replied that all the experiments on riveted joints were with drilled holes (page 249); but in the experiments on perforated plates the holes were half of them drilled and half of them punched (1881, pp. 215–216).

Professor Unwin observed that, in the illustration given by Professor Kennedy of a flat test-bar 3 inches wide, with a central hole drilled through it, the outline would have four edges at which contraction would take place in breaking; whereas an equal bar having a semi-circular notch at each side would present only two edges for the contraction to take place at. Moreover if the latter

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(Professor Unwin.)
bar after fracture were divided longitudinally down the centre, and the pieces were reversed so as to form a central hole, they would not show the same figure as the other bar which had been drilled with a central hole. This illustration therefore he thought entirely supported his own view that a greater contraction of area was concurrent with a lower breaking load.

Professor KENNEDY said that the cases certainly differed in so far as the number of edges was concerned. But what he had found in the experiments alluded to was that there was a real difference in *actual* breaking load taken over *actual* contracted area. It would be remembered that the actual breaking load was a quantity quite different from the maximum load sustained by the specimen.

Mr. EDWARD B. MARTEN asked whether the extra strength in the plate left between the rivets had ever been attributed in punched plates to the extra compression produced in the metal by the punching: though no such explanation would apply to drilled plates.

Professor KENNEDY said he had not offered any such explanation, nor was it one in which he could himself concur; because the increase of tenacity in the perforated plates (p. 238) had been found to be so much greater when the holes were drilled than when they were punched.

The PRESIDENT asked whether the broken specimens from the various experiments had been preserved, and whether they were accessible to the members of the Institution.

Professor KENNEDY said he had preserved all those that he had broken himself. Those broken at University College were accessible there; the larger ones were waiting at Barrow and Birkenhead for further orders.

The PRESIDENT considered the Reports, of which an abstract had been read, recorded one of the best pieces of work that had ever been done under the auspices of the Institution. Engineers wanted

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knowledge on a certain subject, and, with the assistance of Professor Kennedy and the Committee, the Institution had taken the best possible means of obtaining that knowledge. The experiments had furnished results which the members would all agree were extremely valuable, and their value would become more and more appreciated as time went on. He did not think that at present half their true value was known, but in course of time they would be more and more referred to and carried out into practice. These experiments had now occupied more than four years; but in telling what had been done, the abstract just read had omitted to mention certain things. The work of Professor Kennedy and of his assistants had been entirely gratuitous; University College, London, had lent its valuable testing machines gratuitously, as had also the Barrow Hæmatite Steel Co., the Mersey Dock and Harbour Board, and Lloyd's Cambrian Chain Testing House; the Landore Siemens-Steel Co. had supplied the steel freely; and the Wallsend Slipway Co., Messrs. John Penn and Sons, Messrs. G. Wailes and Co., and Messrs. Fielding and Platt had prepared the samples gratuitously, except so far as out-of-pocket expenses were concerned. The whole of the experiments had been reported at four different times, and would be found in the Proceedings. The abstract which had just been read was an epitome of the whole, forming with the Reports themselves a complete record of all that had thus far been done.

He now asked the Members to present a vote of thanks to the Riveting Committee, and especially to Professor Kennedy who had acted for them throughout in the way that had been described.

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DESCRIPTION OF A BLOOMING MILL WITH BALANCED TOP ROLL AT THE EBBW VALE WORKS.

BY MR. CALVERT B. HOLLAND, OF EBBW VALE.

This Blooming Mill, of which the general arrangement is shown in the accompanying diagrams, Figs. 1 and 2, Plates 30 and 31, was seen in course of erection in the steel-rolling mills on the occasion of the visit of the Members of the Institution to the Ebbw Vale Works in August last (Proceedings 1884, page 391). It was completed before the end of last year, but was not started to work till early in the present year. It is intended for reducing the steel ingots from their original section of 14½ inches square to blooms 6 inches square, and nearly six times as long as the ingots. After shearing, the blooms are then reheated for rolling into rails.

Rolls.—The rolls are shown at R in Figs. 3 to 6, Plates 31 to 34. They are 36 inch centres, and contain six grooves, ranging in width from 14½ down to 6⅛ inches. The intervening flanges or collars of 4 inches width are 38 inches diameter in the bottom roll and 33½ inches in the top, giving ¼ inch clearance. The depths of the grooves in the two rolls, and the consequent final heights of openings when the top roll is closed down upon the bottom, are as follows, as shown in Fig. 9, Plate 35 :—

Depths of grooves	Top roll . .	4¾	3¾	2¾	2¾	1¾	1¾ inches.
	Bottom roll .	7	6	5	5	4	4 „
Clearance between collars .		¼	¼	¼	¼	¼	¼ „
Final heights of openings .		12	10	8	8	6	6 „
Widths of grooves . .		14½	12¼	10¼	8⅛	8⅛	6⅛ „
Final areas of openings .		174	122	82	65	49	37 sq. ins.

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BLOOMING MILL.

Plate 30.

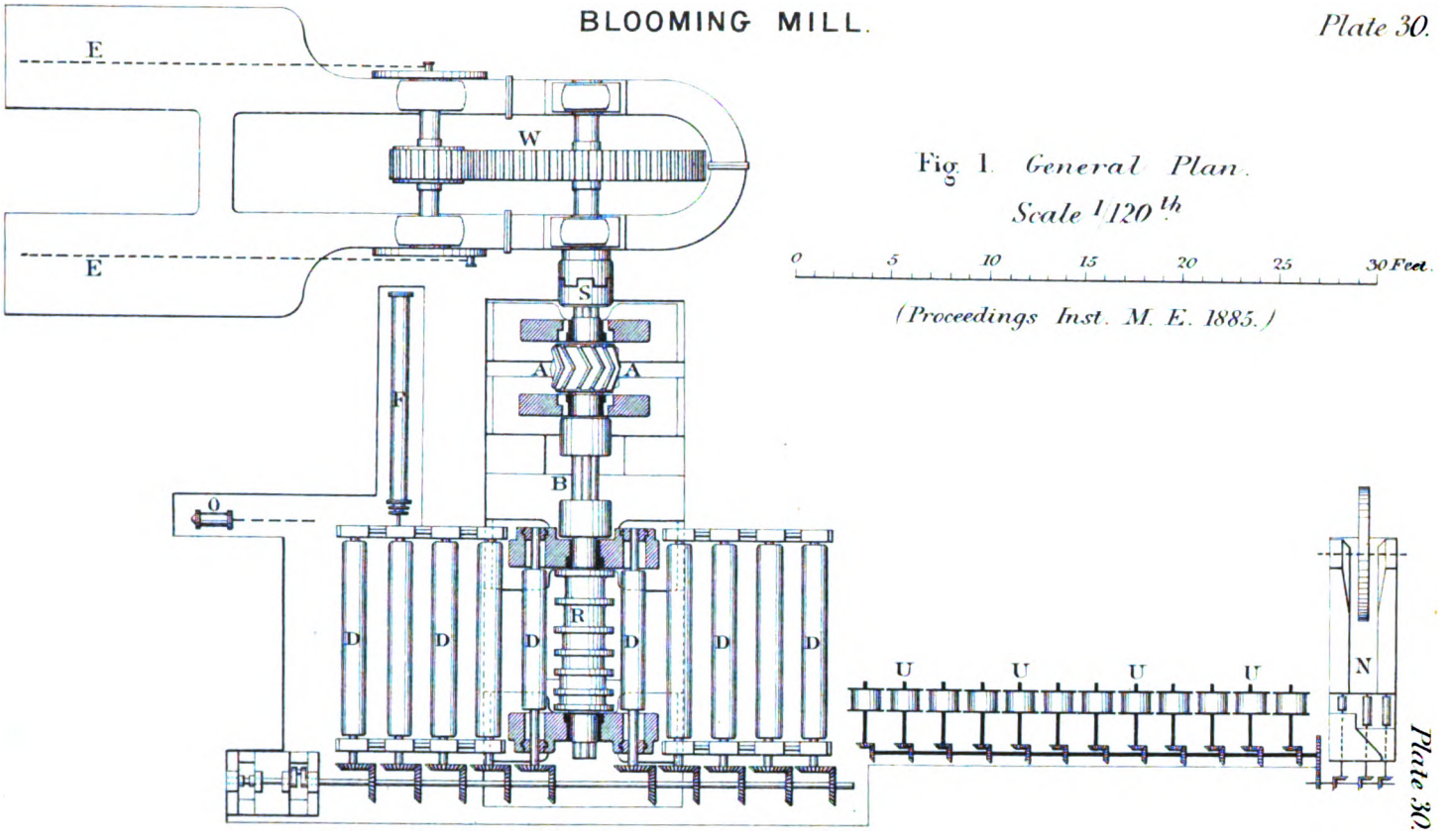

Fig. 1. *General Plan.*
Scale 1/120th

0 5 10 15 20 25 30 Feet.

(Proceedings Inst. M. E. 1885.)

Plate 30.

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BLOOMING MILL.

Plate 31.

Fig. 2. *General Longitudinal Section.*
Scale 1/120th

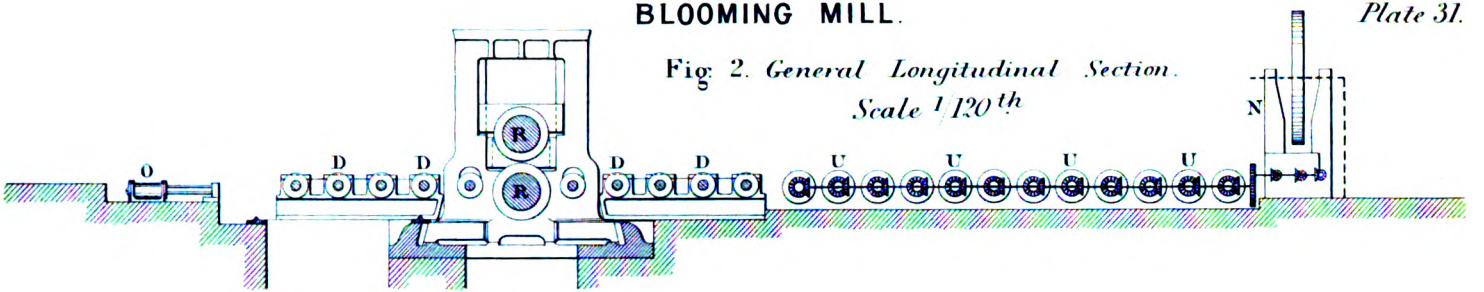
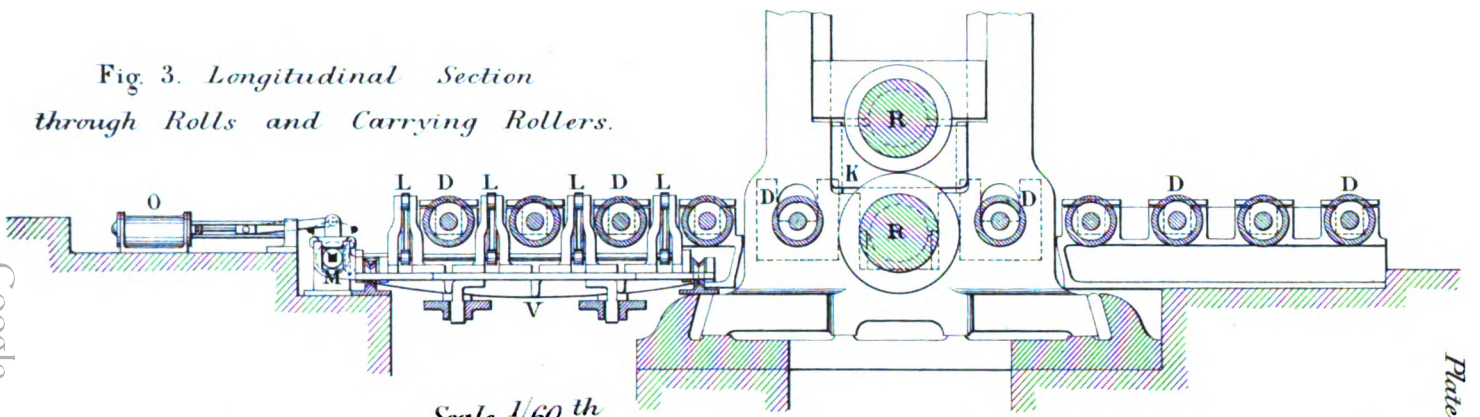


Fig. 3. *Longitudinal Section through Rolls and Carrying Rollers.*



Scale 1/60th

0 5 10 15 20 25 Feet.

(Proceedings Inst. M.E. 1885.)

Plate 31.

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Fig. 4. *Plan of Rolls and Carrying Rollers.*

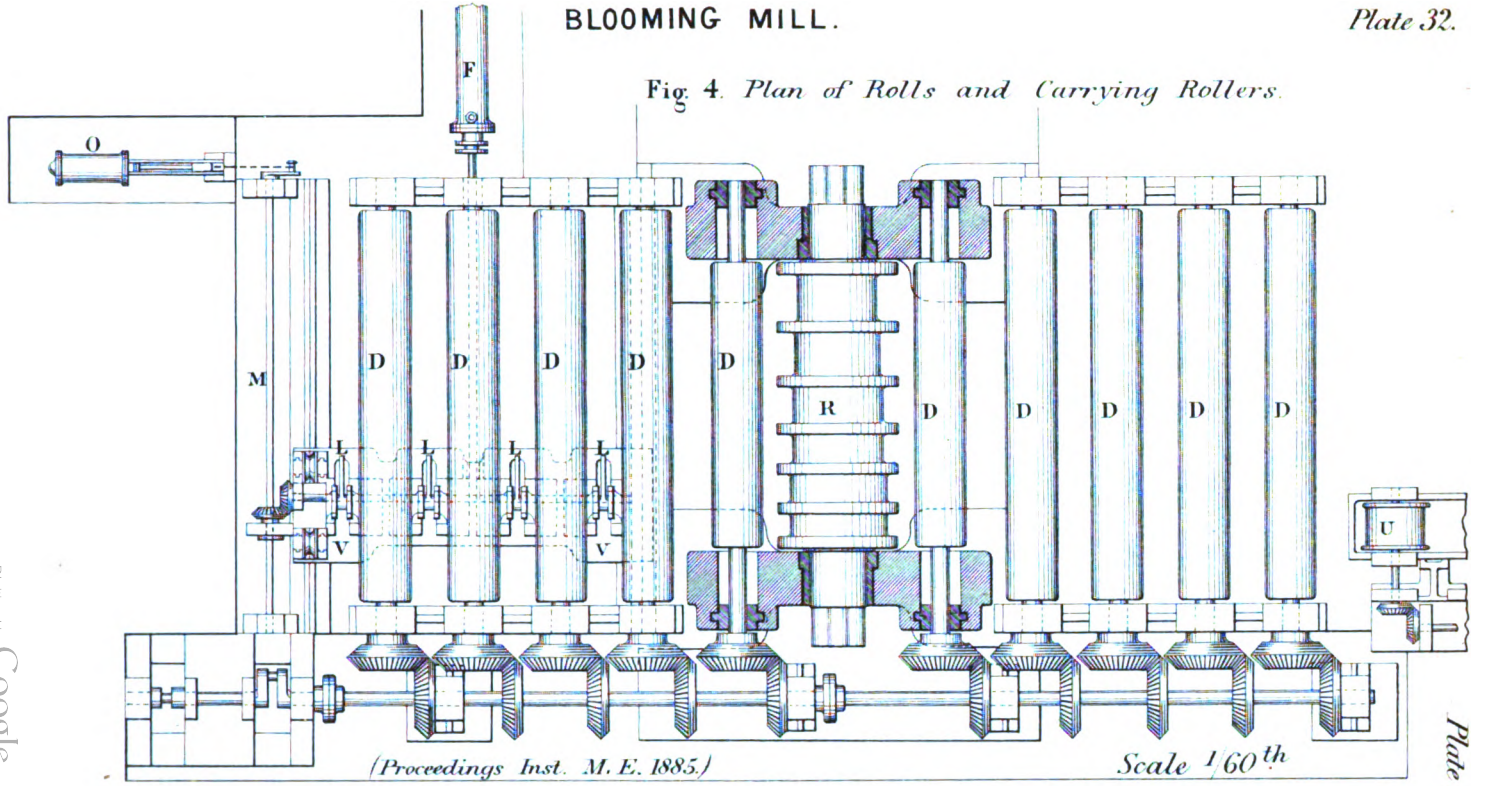

Plate 32.

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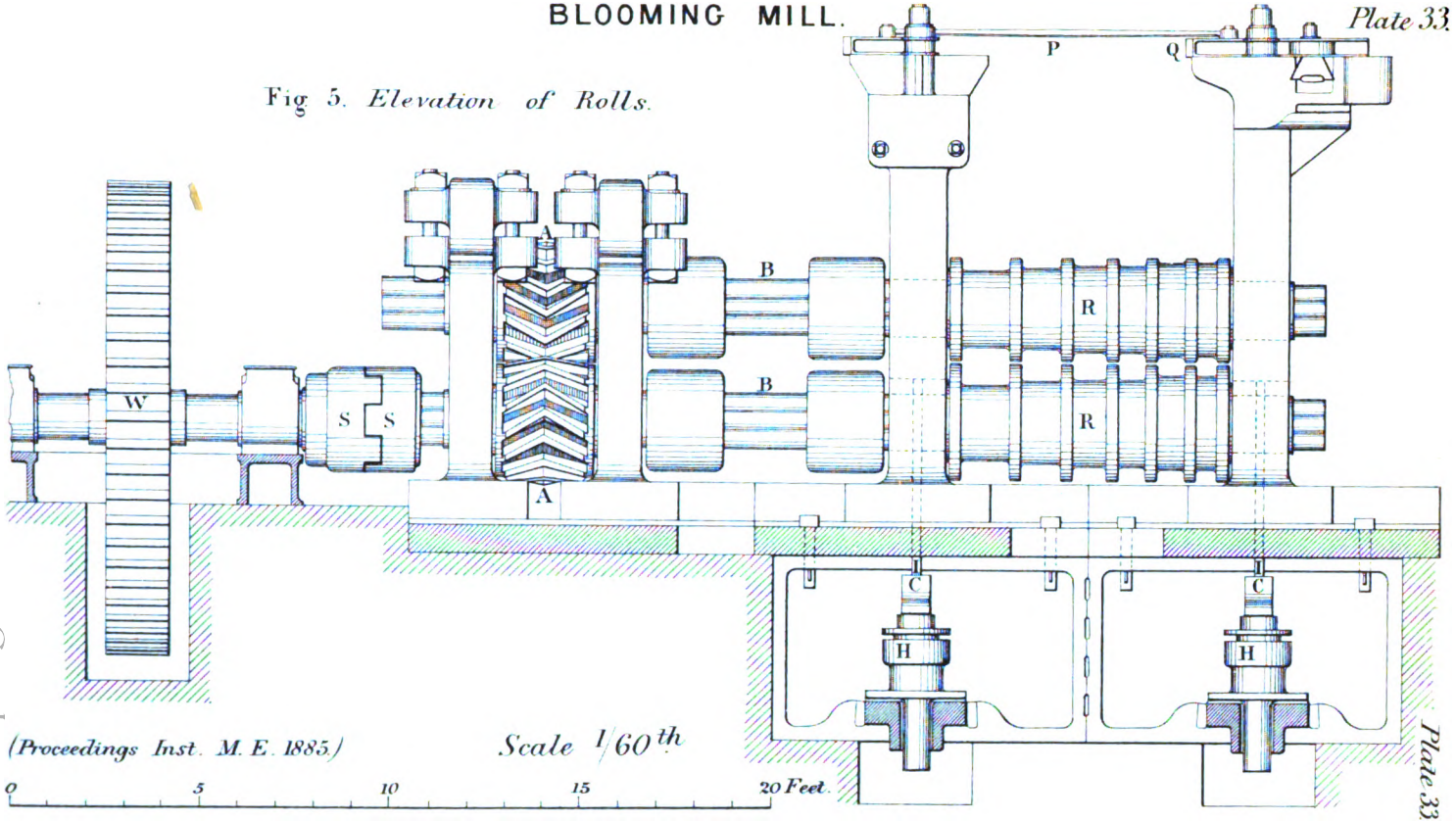
BLOOMING MILL.

Plate 33.

Fig 5. *Elevation of Rolls.*



(Proceedings Inst. M. E. 1885.)

Scale 1/60th

0 5 10 15 20 *Feet.*

Plate 33.

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BLOOMING MILL.

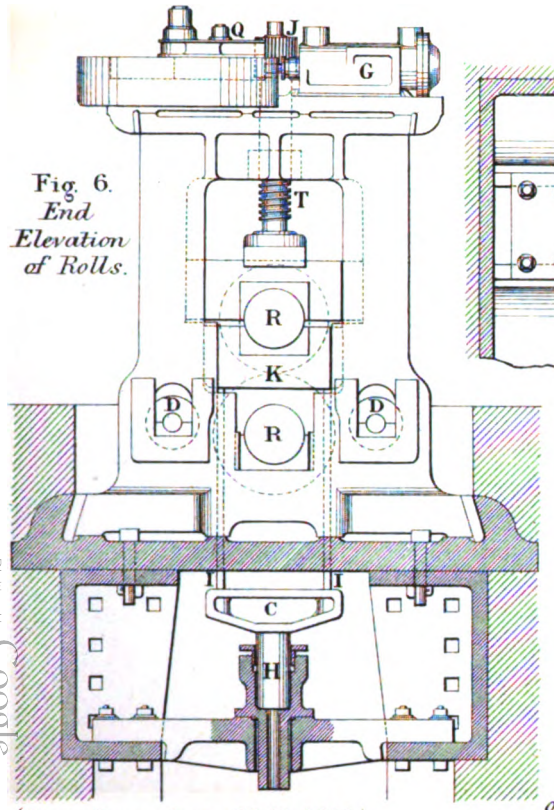

Fig. 6. *End Elevation of Rolls.*

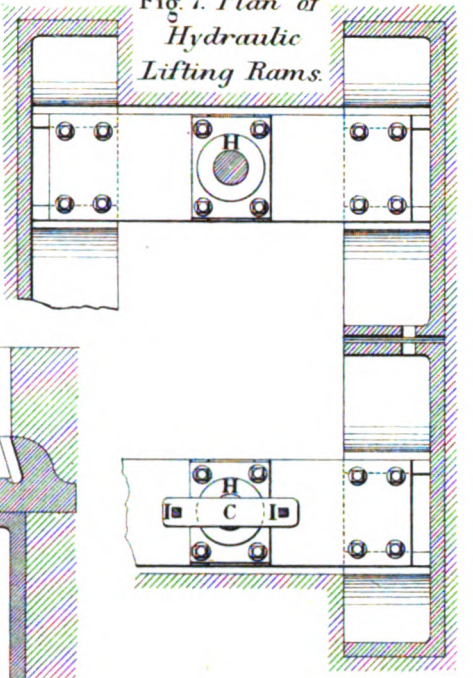

Fig. 7. *Plan of Hydraulic Lifting Rams.*

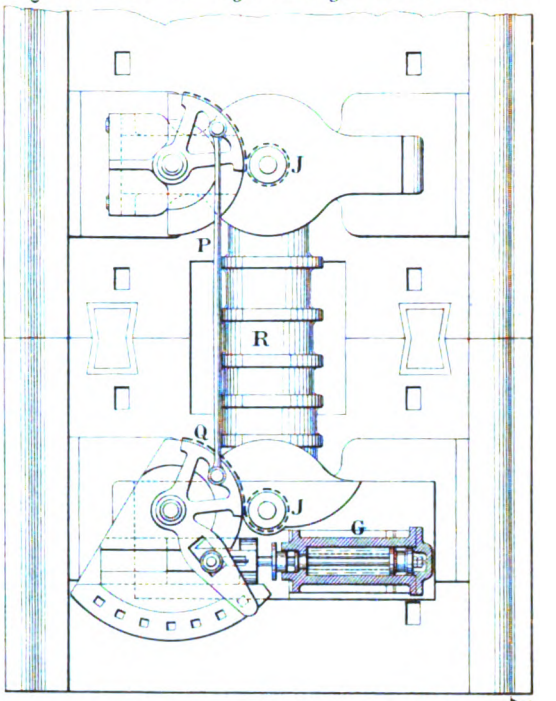

Fig. 8. *Plan of Tightening-down Gear.*

Scale 1/60th

0 5 10 15 20 Feet.

(Proceedings Inst. M.E. 1885.)

Plate 34.

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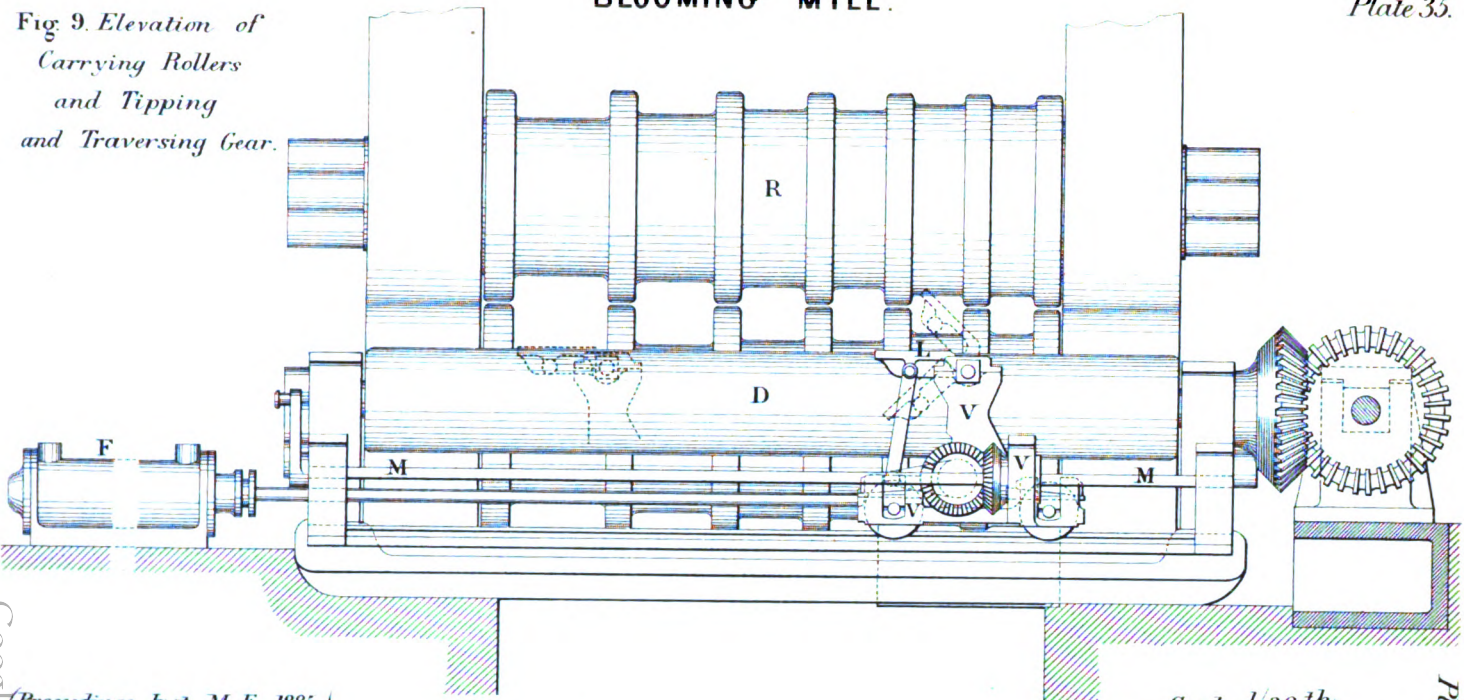
BLOOMING MILL.

Plate 35.

Fig. 9. *Elevation of Carrying Rollers and Tipping and Traversing Gear.*



(Proceedings Inst. M. E. 1885.)

Scale 1/30 th

Inches 12 6 0 5 10 15 Feet.

Plate 35.

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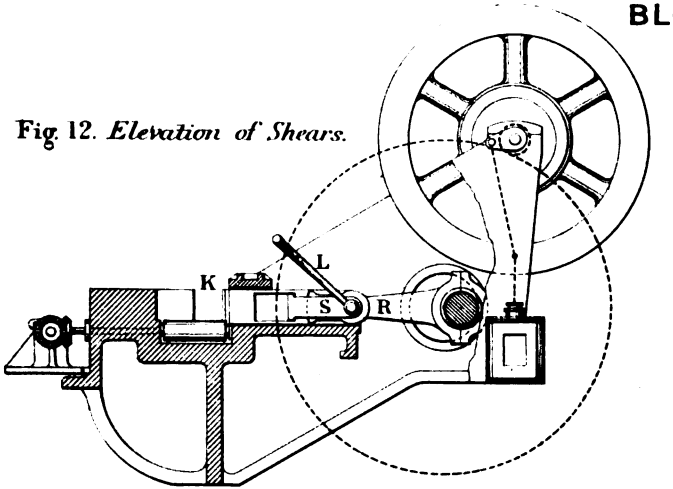
Fig. 12. *Elevation of Shears.*



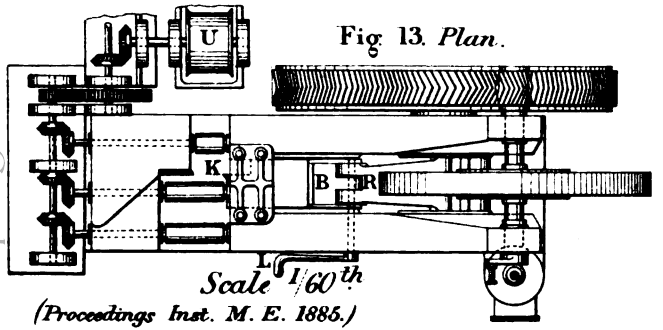
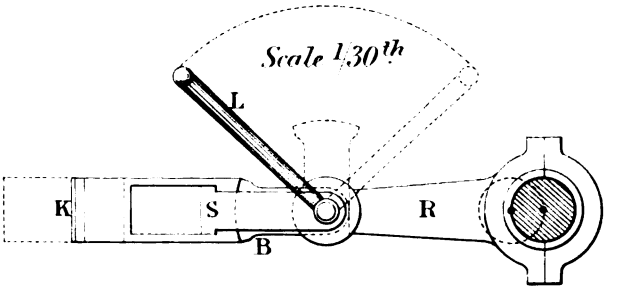


Fig. 13. *Plan.*

Scale 1/60th

(Proceedings Inst. M. E. 1886.)

Fig. 14. *Tilting Distance-Block.*



Pinion with Helical Teeth.

Fig. 10.

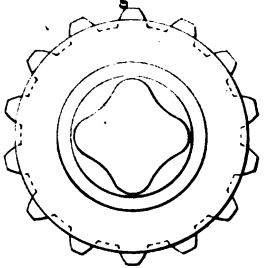
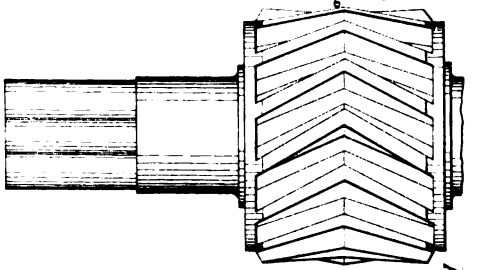


Fig. 11.



Scale 1/30th

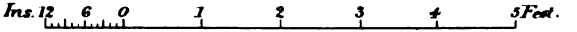


Plate 36.

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The ingot has to pass four times through each of the first and second grooves. The top roll is raised for the first pass, and lowered for the second; the bar is then turned on edge, and the top roll raised for the third pass; and for the fourth the roll is again lowered. The bar passes twice through each of the four succeeding grooves, the top roll closing on the bottom in each case for the second pass. The speed of the rolls ranges from 18 to 24 revolutions per minute.

The rolls are made of Nos. 5 and 6 Welsh foundry pig, and were cast and turned at the works. Their clear length between the bearings is 7½ ft., and their length over all is 12½ ft. The weight of the bottom roll is 9½ tons, and of the top roll 8¾ tons.

Instead of being only partly counterbalanced by the ordinary levers, the weight of the top roll is much more than wholly counterbalanced by means of a pair of hydraulic lifting rams HH under constant pressure, Figs. 5 and 6, Plates 33 and 34, which are placed upright beneath the bedplate of the roll standards, one under each standard. The rams are each 10⅜ inches diameter, and the water pressure upon them is 450 lbs. per sq. inch, giving a total lifting pressure of 34 tons. In Fig. 7 is shown a plan of the girders for supporting the rams. On the head of each ram is a crosshead C, carrying a pair of wrought-iron pillars II, 2½ inches square, which pass up through the bedplate and standard, and support the keep or under-carriage K of the top roll, Fig. 6. Hydraulic pressure is also employed for tightening the top roll down by means of a horizontal hydraulic cylinder G, Figs. 6 and 8, of 9 inches diameter and 2 feet stroke, fixed on the top of one standard. The piston-rod works a toothed quadrant Q, Fig. 8, centred on the standard, and gearing into a steel pinion J keyed on the top of the tightening-down screw T, Fig. 6; a similar quadrant and pinion work the screw in the other standard, and the two quadrants are coupled together by a wrought-iron connecting-rod P from standard to standard. The tightening-down screws are each 10 inches diameter over the threads, with 2 inches pitch. One revolution suffices for the whole vertical range required for the roll. The advantage of the counterbalancing arrangement is that the top roll is thereby lifted automatically, whenever the

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tightening-down screws are withdrawn by reversing the valve of the cylinder G that works them. Thus one movement of a single handle serves to slack back equally the pair of tightening-down screws and raise the top roll simultaneously. Greatly increased facility is thereby obtained in entering the ingot between the rolls for its successive passes.

Engines and Gearing.—The rolls are driven by a pair of high-pressure horizontal reversing engines at EE, Fig. 1, Plate 30, made by Messrs. Galloway and Sons, Manchester, having cylinders of 36 inches diameter and 4½ feet stroke, and geared three to one by a pinion of 3 ft. $11\frac{5}{32}$ ins. diameter on the engine shaft, gearing into a spur wheel W of 12 ft. $2\frac{3}{32}$ ins. diameter in line with the bottom roll. The engines are reversed by a hydraulic reversing cylinder of 5 inches diameter and 12½ inches stroke, which controls the reversing links of the engines in the usual way. The spur wheel W is connected with the rolls by a pair of steel clutches S, Fig. 5, Plate 33, a pair of steel pinions AA with helical teeth, and the usual breaking spindles and couplings BB. The pinions AA with helical teeth are secured in gear with each other by cast-iron riders and bolts 5 inches diameter; the teeth, as shown in Figs. 10 and 11, Plate 36, are 8 inches pitch and 4 inches high, and are set helically in opposite directions on each side of the centre line of the rim, the two sets of teeth making an angle of 120° with each other or of 30° with the axis of the pinion. So made, the teeth work smoothly together in continuous contact, free from backlash, so that there is neither jar nor noise in reversing. The engine-pinion and spur wheel W have ordinary straight teeth of 8·23 inches pitch.

Tipping and Traversing Gear.—In Figs. 3, 4, and 9, Plates 31, 32, and 35, are shown the carrying rollers DD for feeding the ingot into the rolls and receiving it as it quits them. There are five carrying rollers in front of the rolls, and five behind; all of them are 16 inches diameter, and are spaced $26\frac{3}{4}$ inches apart centre to centre, excepting the innermost pair which are spaced 28½ inches from the next. They are all driven by mitre wheels from a pair of vertical engines, with 10-inch cylinders and 14 inches stroke.

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Beneath the carrying rollers in front of the rolls runs a traversing carriage V, Fig. 9, Plate 35, pushed across and drawn back again at pleasure by means of a horizontal hydraulic cylinder F of 8 inches diameter and 6 ft. 2 ins. stroke, the piston-rod of which is attached direct to the carriage. On the carriage are mounted four tipping levers L, which work in the spaces between the carrying rollers, and are elevated or depressed by connecting links from arms on a shaft beneath. By this means the tipping levers are either kept down below the level of the carrying rollers, so as to be clear of the ingot passing through the rolls; or are held horizontal for supporting the ingot clear of the carrying rollers, while traversing it laterally from groove to groove of the rolls; or are tilted up at an angle of 45° above the carrying rollers, for tipping the ingot over sideways through 90°, so as to roll it alternately edgeways and flatways in the successive grooves of the rolls. These three several positions of the tipping levers are shown by the full and dotted lines in Fig. 9. The shaft which tilts them is mounted on the traversing carriage V, and is worked by a mitre wheel on one end; this wheel gears with another mitre wheel, mounted in bearings in the carriage, and sliding loose along a square rocking shaft M, Figs. 3 and 4, which is placed parallel with the travel of the carriage; on the end of the shaft M is a crank arm, which is rocked forwards or backwards to the desired extent by means of a hydraulic cylinder O of 6 inches diameter and 16 inches stroke. Both this tipping movement and the traversing movement of the carriage are controlled by independent hand-levers, worked separately by one man in accordance with the requirements of the rolling as it progresses.

Live Rollers.—From the rolls the blooms are conveyed to the shears N by a train of twelve live rollers U, Figs. 1 and 2, Plates 30 and 31, 19 inches diameter and 13 inches wide, spaced 24 inches apart centre to centre, and driven by mitre wheels from a pair of vertical engines with cylinders of 6½ inches diameter and 10 inches stroke, which are geared two to one with the longitudinal shaft carrying the mitre wheels.

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Shears.—As shown in Figs. 12 and 13, Plate 36, the shears are horizontal, and the knife K has a stroke of 10 inches, given by a vertical engine with cylinder of 12 inches diameter and 15 inches stroke, geared 9½ to 1. In the connecting-rod R working the knife K is centred a distance-block B, Fig. 14, through which the thrust is transmitted to the knife in the forward stroke. By tilting the block out of gear by means of the hand-lever L, as shown dotted in Fig. 14, the knife is thrown out of action at any time without stopping the engine. In the return stroke the knife is drawn back by a pair of straps S upon the end of the connecting-rod. The shears were made at the works.

Discussion.

The PRESIDENT said that Mr. Holland regretted he was not able to be present; but Mr. Thomas Wood, the engineer of the works, had come for the purpose of giving any additional particulars.

Mr. THOMAS WOOD said the mill had been at work during the last six months, though there was not as much work for it at present as it could do. It was working very satisfactorily, and was saving four men.

The PRESIDENT noticed that the steel pinions driving the top roll had helical teeth, while the main spur-wheel and the engine pinion had ordinary straight teeth, not helical. Also that the pinions with helical teeth, both those on the rolls and those on the shears, had shrouding or feathers; while the main spur-wheel and engine pinion

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with straight teeth had not. After a good deal of experience he had himself found that feathers on wheels in rolling-mill machinery were far more trouble than they were worth; because if there was the slightest shifting of a wheel or pinion on its key-bed, as often happened, it began chopping away on the feathers; and the feathers were as often a source of breakage and trouble as of saving. Again, if any repairs were going on, sometimes a spanner was left in the teeth, or other things of that sort. If there were no feathers, such misplaced articles had a good chance of working out; but where there were feathers, they were pocketed in the wheel, as it were, and would probably cause a smash. The wheels he thought were also truer without the feathers, because feathers caused trouble in moulding; and better wheels could be made without feathers than with them.

There was no question whatever as to the great value of helical teeth. They kept engaged longer than parallel ones, and each half of a tooth supported the other half. They were far stronger, and in fact they served the purpose of feathers in a better way, as each half tooth might be looked upon as a strut to its fellow half. It had struck him that there was some inconsistency in designing the gearing of the mill, feathers being employed in some wheels and not in others, helical teeth in some and not in others, cast-iron for some and steel for others. If he had his way, he should make them all with helical teeth, all without feathers, and all of steel.

Mr. William Schönheyder thought the mode of working the tightening-down screws was rather roundabout, by conveying the power from the hydraulic cylinder, first to a lever, then to a quadrant and connecting-rod, and then to the pinions on the tops of the screws. He suggested that by placing the hydraulic cylinder in the line of the present connecting-rod, and by having a rack upon the piston-rod to work the pinions on the screws, the extra gearing would have been saved. It seemed to him an objectionable plan for the piston-rod to actuate the lever by a sliding block in an oblique slot, in which the block would be tending to slip first one way and then the other.

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Mr. Wood said the reason why the wheels with straight teeth, not helical, had been put in the mill, as shown, was that they happened to be in stock. There was another mill at the works, exactly like this as far as the gearing was concerned; and the wheels had been put exactly the same for the two mills, so as to have duplicates. The gearing for actuating the tightening-down screws had been found to work very well, and there had been no trouble with it.

The President observed that near the quadrant working the tightening-down screw there appeared to be some square holes in the casting on the top of the roll standard; he supposed they were meant for the insertion of stops.

Mr. Wood replied that pegs covered with india-rubber were stuck in the holes to stop the travel of the hydraulic piston, according to the varying extent of tightening-down required for the successive passes through the rolls.

The President considered the paper a valuable one, and had no doubt the mill was a good one throughout, and did its work thoroughly well and efficiently, and was quite up to date. Mr. Holland had certainly applied hydraulic and steam power wherever it could be done. Driving with the Ramsbottom reversing engines, as in this instance, was now superseding all other plans for rolling-mill work; and there could be no question that it did the work far better. When first introduced, it had been supposed that reversing engines would take a great deal more steam; but practice had shown that they took less steam, because they might either stand still or just creep gently round during a considerable portion of the time. Here too Mr. Holland, having no doubt got hydraulic power all over the works, was applying it to balancing the rolls, which was not everywhere possible. This certainly seemed a much better plan than the old one of having levers and balance-weights down in a pit below, which were always slipping, bending, breaking, and getting wrong, and were very difficult to put right. The method shown seemed a very neat and good plan to adopt. Then there

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was the handling of the ingots, not only to and fro into the rolls and back out of them and forward to the shears, but also sideways by means of the traversing and tipping gear for lifting them up, carrying them across, and turning them over. All this gear seemed to be very neat and efficient, and no doubt it would do good work, far better than hand labour. On the whole he was of opinion that the mill, while utilising machinery which happened to be already in stock, was still a very good mill; and certainly Mr. Holland and Mr. Wood deserved the thanks of the members for bringing it before them.

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MEMOIRS.

Alan Charles Bagot, second son of Col. Charles Bagot, was born at Elford near Tamworth on 1st June 1856, and died at Bournemouth on 22nd April 1885, in his twenty-ninth year, from consumption brought on by an accident in a Welsh mine in 1880 and by over-work and exposure in his profession. He was educated at Eton and at Pembroke College, Cambridge; and at both places was demonstrator in the chemical laboratories. Afterwards he devoted himself to mining and electrical engineering, and especially to inventions and appliances for saving life in mines. He was engaged in experiments for the late Mr. John Taylor; and was chief electrical engineer and partner in the firm of Messrs. Apps and Co., London. He was the inventor of a safety indicator for mines; and the author of treatises on accidents in mines and on the principles of colliery ventilation. During the last ten years he was much concerned with the application of electricity to coal mining, with safety-lamps, and with appliances for use in mines. In 1876 he was engaged in experimenting on spontaneous combustion in coal, cotton, and wool; and invented an electric detector. In 1877 he introduced a block system of electric signalling; and in 1883 an automatic electric transmitter. During his connection with Messrs. Apps and Co. he brought out improvements in electrical apparatus, including a portable set of resistance coils for use on railways and for torpedo work. In consequence of his accident and ill-health, he retired from the firm early in 1884. He was one of the conservators of the river Trent, and honorary consulting engineer to that body; and he published a series of papers on the prevention of floods. He was the inventor of an automatic electrical air-recorder for mines, and promoted the substitution of self-extinguishing safety-lamps in place of Davy and Clanny lamps, as well as increased care and efficiency

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in the lamp rooms of collieries. He was presented with two gold medals for saving life at the risk of his own; and his thoughts were engrossed by the endeavour to prevent the lamentable loss of life in coal mines through carelessness or ignorance. His latest work, on the principles of civil engineering as applied to agriculture and estate management, was written during severe bodily suffering in the last months of his life. He became a Graduate of the Institution in 1879, and a Member in 1882. In 1879 (Proceedings, page 219) he contributed a paper on the construction and comparative merits of the safety-lamps generally in use; and in 1883 (Proceedings, page 421) a paper on the application of electricity to the working of coal mines.

Thomas J. Perry was born at Bilston on 9th November 1824, and died on 29th March 1885, in the sixty-first year of his age. He was the only surviving partner of the firm of Messrs. Thomas Perry and Son, ironfounders and engineers, Highfields Works, Bilston, having on the death of his father become sole proprietor of the works. Taking great interest in the development of the iron and steel trades, he was much engaged in making and perfecting machinery employed in the various operations and experiments connected with the Danks process. In the manufacture of blowing and pumping engines he was largely occupied, and supplied the greater part of the blowing engines for the Barrow Works. He paid special attention to improving the quality and strength of foundry castings used in the construction of all iron and steel rolling machinery, particularly chilled rolls for rolling iron and steel plates and other purposes, for which his rolls were held in very high esteem. He was the first who adopted a perfectly unique method of testing the absolute strength of all pig iron while in the pig, however rough the form or variable the size or quality. The pig itself is broken at 3 feet bearing in a hydraulic press, the actual load being recorded by a self-registering pressure-gauge; the transverse sectional area at the fracture is measured in square inches by taking a rubbing from it; and the strength is reduced by calculation to the common standard of a bar one inch square similarly broken at 3 feet bearing. A

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uniformly accurate comparison is thus obtained between all varieties of pig, instead of depending on the rough conjecture obtained by breaking with a blow of a hammer or throwing on a breaker. He was chairman of the South Staffordshire Ironfounders' Association from its commencement, and a county magistrate; and had been a Member of the Institution from 1863.

JOSEPH D'AGUILAR SAMUDA was born in London in 1813, and early became a pupil of his elder brother, Jacob Samuda, with whom he entered into partnership as an engineer in 1832. The firm were at first principally engaged in marine-engine building, but in 1843 shipbuilding was added to the business; and from 1842 to 1848 he was engaged in carrying out, on the Kingstown and Dalkey, Croydon, South Devon, and Paris and St. Germains lines, the atmospheric railway on the plan of his elder brother and Mr. Samuel Clegg. From 1851 he occupied himself almost exclusively in iron and steel shipbuilding, and constructed a large number of vessels for most of the principal navies and leading mercantile companies. Amongst them may be mentioned the "Thunderbolt," the first armour-cased iron vessel built; the "Prince Albert," the first iron-clad cupola ship built; and the "Mortar Float No. 1," the first iron mortar vessel built. More recently he built two very fast steel vessels, the "Albert Victor" and the "Louise Dagmar," each 1040 tons burden and 2800 H.P. with a speed of 18½ knots per hour, for the Channel service between Folkstone and Boulogne; and subsequently the "Mary Beatrice" with a speed of 19 knots per hour. Of late years the principal part of his work was the construction of armour-clad vessels, the most recent being the Brazilian turret ships "Riachuelo" and "Aquidaban." In 1860 he assisted in the formation of the Institution of Naval Architects, of which he was subsequently a Vice-President. In 1864 he became a Member of this Institution. In 1865 he entered parliament as member for Tavistock; and in 1868, and again in 1874, he was elected to represent the Tower Hamlets. He died on 27th April 1885 at the age of seventy-one.

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Institution of Mechanical Engineers.

PROCEEDINGS.

August 1885.

The Summer Meeting of the Institution was held at Lincoln, commencing on Tuesday, 4th August 1885, at Ten o'clock A.M.; Jeremiah Head, Esq., President, in the chair.

The Members were received in the Masonic Hall by the Mayor of Lincoln, Francis Jonathan Clarke, Esq.

The Mayor said that during the time he had occupied the position of chief magistrate of the city of Lincoln he had had many pleasing duties to perform; but he had never had one which had given him more pleasure and gratification than that of welcoming, as he now did on behalf of his fellow citizens and himself, the President and Members of the Institution of Mechanical Engineers. Perhaps no city in England of the same size had greater cause to be proud of the engineering abilities of the country than Lincoln. From a sleepy cathedral town it had risen in a few years to a manufacturing centre of no mean importance. He had no doubt that the Members of the Institution would find many things to interest them in Lincoln and the neighbouring towns; and on behalf of the Reception Committee he would assure them that every endeavour would be made to enhance as far as possible the pleasure and enjoyment of their visit to this grand old city.

The President replied that, on behalf of himself, the Vice-Presidents, the Council, and the Members of the Institution of Mechanical Engineers, he desired to thank the Committee for the hearty reception they were giving to the members, and the Mayor of

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(The President.)
Lincoln for the kind expressions with which he had welcomed them. When the Local Committee first invited the Institution to visit Lincoln, the Council accepted the invitation with eagerness. They did so because many of them knew that the attractions of Lincoln were of no mean order. Lincoln was a city full of antiquities. It had a Roman archway which was probably nearly two thousand years old; it had a Cathedral and a Castle, which were built many centuries ago; and its streets contained several ancient buildings, every stone of which, if it had the power of utterance, could tell something about the times of their forefathers, and the various feuds and struggles in which they had been engaged. But he did not suppose that the antiquities of Lincoln would alone have induced the Institution of Mechanical Engineers to visit the city on this occasion. They were visiting it, because they knew that its attractions from an engineering point of view were also of an unusual character. Lincoln, while keeping touch with antiquity, had kept abreast of modern needs and modern science; and it was to the latter that the members of the Institution more particularly devoted themselves. They did not forget that the names of Clayton and Shuttleworth, Ruston and Proctor, Robey, and Foster, were known throughout the world wherever civilisation existed. The members wanted to visit the works of these celebrated firms, and to get some wrinkles from them; and if in going round they were able to give any wrinkles in return, they would be delighted to do so. They also had the ambition to have upon their muster-roll the names of all the engineers of position in the country; and they hoped by their visit to Lincoln to interest many to whom they were perhaps but little known as yet. He begged again to thank them for the kind and hearty welcome given to the members on this occasion of their visit to Lincoln.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and the following thirty candidates were found to be duly elected:—

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MEMBERS.

William Henry Allen,	London.
George Frederick Charnock,	Bradford.
John Cochrane,	Glasgow.
Charles Duckering,	Lincoln.
Arnold Goodwin, Jun.,	London.
Frederick Henry Harrison,	Lincoln.
William Howarth,	Oldham.
John Clarke Johnson,	Wednesbury.
George Kendall,	Newport, Mon.
Hector Kidd,	Sydney.
Frank Lister,	Keighley.
John McNeil,	Glasgow.
Thomas Rees Morgan,	Alliance, Ohio, U.S.
Sir Reginald Louis Oakes, Bart.,	York.
Henry John Rogers,	Watford.
Edward Snowball,	Taranaki.
John Armstrong Snowdon,	London.
Matthew Stirling,	Hull.
Thomas Brynalyn Trueman,	Buenos Aires.
Henry John Warren, Jun.,	Venezuela.
William Warren,	Venezuela.
James George Whitehead,	Callao, Peru.
Thomas Wood,	Ebbw Vale.
Albert Wootton,	Loughborough.

GRADUATES.

Frederick Henry Addis,	London.
Harry Allcard,	Sheffield.
Gerald Vaughan Burrowes,	London.
Jodoo Nauth Dutt,	London.
Archibald Potter Head,	Newcastle-on-Tyne.
Thomas Egerton Keyworth,	Lincoln.

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The PRESIDENT then delivered his Address: after which the following Papers were read and discussed:—

Description of Dunbar and Ruston's Steam Navvy; by Mr. JOSEPH RUSTON, M.P., of Lincoln.

On recent adaptations of the Robey Semi-Portable Engine; by Mr. JOHN RICHARDSON, of Lincoln.

On the proposal of the President the discussion of the latter paper was postponed till after the reading of Mr. Nevile's paper, in order that the two might then be discussed together.

At One o'clock the Meeting was adjourned to the following morning.

In the evening there was a Special Musical Service in the Cathedral at Half-past Seven o'clock, by invitation of the Dean and Chapter; and an Address was delivered to the Members by the Bishop of Lincoln.

The ADJOURNED MEETING was held in the Masonic Hall, Lincoln, on Wednesday, 5th August 1885, at Ten o'clock A.M.; JEREMIAH HEAD, Esq., President, in the chair.

The following Papers were read and discussed:—

On Private Installations of Electric Lighting; by Mr. RALPH H. C. NEVILE, of Wellingore.

On the Iron Industry of Frodingham; by Mr. GEORGE DOVE, of Frodingham.

Description of the Tripier Spherical Eccentric; by M. LOUIS POILLON, of Paris.

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The President proposed the following Votes of Thanks, which were passed by acclamation:—

To the Local Executive Committee—especially the Chairman, Mr. Clayton; the Vice-Chairmen, Mr. Hornsby, Mr. Marshall, Mr. Ruston, and Mr. Shuttleworth; the Honorary Secretary, Mr. Clench; and the Secretary, Mr. Watson—for the excellent arrangements made by them to ensure the success of this Meeting of the Institution, and for the hearty and hospitable welcome prepared for the Members during their visit to Lincoln, and throughout their Excursions to Grantham, Newark, Gainsborough, and Doncaster.

To the Local Committees at Frodingham and Grimsby, for the kind and friendly receptions arranged at those places.

To the Authorities of the Great Northern, the Manchester Sheffield and Lincolnshire, the Midland, and the Great Eastern Railways, for the special free Excursion trains placed by them at the disposal of the Institution.

To the Proprietors of the various Works, which the Members have been freely invited to visit in Lincoln and in the course of the Excursions.

To the Right Rev. the Lord Bishop of Lincoln, the Dean and Chapter of Lincoln Cathedral, the Vicar of Grantham, Sir Hickman Beckett Bacon, Bart., and the Witham Lodge of Masons, for the several cordial invitations given by them in connection with the Meeting.

The Rev. Sub-Dean Clements desired, in acknowledgment of the last of the votes of thanks which had just been passed, to express his own feeling of the kindness of that vote, and he thought also the feeling of the Dean and Chapter, who regarded it as a pleasure and honour if they had contributed to the success of the visit of the Institution to Lincoln. As trustees of a great ecclesiastical building, and as representing a great ecclesiastical corporation, it was and always must be a pleasure to a Dean and Chapter to do everything they could to receive such a body as the Institution, on the slightest intimation that it would be their desire to attend such a service as had been arranged for the members on the previous evening. He could only say that, while the Dean and

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(Rev. Sub-Dean Clements.)

Chapter regretted that the capacity of the choir was not as large as they could have wished it to be for the sake of receiving their fellow citizens, the working men of the city, with whom they lived and hoped always to live on terms of amity and affection, yet at the same time they had done their very best to include all, and he thought the choir could scarcely have held half a dozen more people than it contained on the previous evening. He was certain that the conduct of the people who were excluded for want of room, and who yet remained for the service, was beyond all praise. All must bear witness that among those outside the choir the quietness and attention manifested during the whole of the service were most gratifying, and showed what was lost from the capacity of the choir being as small as it was. He begged to thank the President and Members for the vote which had just been passed, and to express the gratification of the Dean and Chapter at having in any way contributed to the success of the visit of this important Institution to the ancient city of Lincoln.

The Meeting then terminated. The attendance was 224 Members and 118 Visitors.

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ADDRESS OF THE PRESIDENT,

JEREMIAH HEAD, Esq.

It has long been customary for the President of the Institution of Mechanical Engineers to open the proceedings at the summer meeting by giving an address; and this obligation I am now with much diffidence about to attempt to fulfil. I do not forget that the leniency and loyalty towards the chair, which have always prevailed among you, permit your President's observations to pass without the ordeal of subsequent discussion. To one who has long been accustomed to encounter, in ordinary debate, the risk of verbal demolition by some critical member, the advantage of being for once "six feet above contradiction" is somewhat tempting. I trust however I shall not be found in the end to have abused your indulgence, or to have tried your patience too severely. I shall endeavour to discuss freely and fairly the questions which arise, not claiming that my views are incontrovertible, nor that I am more free from bias than humanity generally. But I feel sure I may ask you to give me credit for having at heart no other object than to aid, so far as my limited powers and opportunities admit, the true progress of Mechanical Engineering.

It was perhaps but natural that I should in the first place refer to some of the many able and interesting addresses to which you have on former occasions listened from Past-Presidents, in order to find, if possible, a guiding principle pervading all, whereon I might frame my own. But in this search I was not very successful. Previous addresses have been perhaps most usually of a historical character, recording progress in some branch or branches of mechanical science with which the writer was especially conversant.

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In the earlier days of engineering it was possible every few years to give, with some approach to completeness and within the limits of an address, a more or less complete résumé of the past, a description of the present, and an indication of the future. The immense development however of the applied sciences in recent years has made this increasingly difficult. No one can now do more than *aim at* "knowing something of everything, and everything of something." I say "aim at," because attainment of perfection in the narrower sphere, and of universality in the wider, is equally impossible. The great mass of technical literature published now-a-days, which inevitably and punctually arrives to flood the office of every known engineer, is almost bewildering. The supply of information and facilities for circulating it seem to be fast getting out of proportion to the time, the brain-power, and the eye-sight of the most energetic readers. The book-shelf and even the waste-paper basket are I fear too often or too immediately the sources of relief. Many a paper, article, and book has to be put aside with a sigh till a more convenient season, which perhaps never arrives. And so it comes that every engineer must feel more and more as he grows older that he knows but very little even of his own profession.

Relative Advantages of Iron and Steel.—Living as I happen to do in one of the most important iron-producing districts of the country, and connected as I have long been with the manufacture of iron, and latterly of steel, I have naturally felt a keen interest in a question which has not infrequently arisen at our meetings, and still more often at those of a kindred institution. The question I refer to is that of the relative advantages of Iron and Steel for constructive purposes: with which is necessarily associated the wide-spread popular expectation that the older material is on the point of being completely superseded in every direction. I propose to occupy the time at my disposal by discussing, though of course only in the most general and incomplete manner, certain points connected with this great and still unsettled question, in the hope that a few observations thereon may prove not altogether uninteresting

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or useless, though admittedly expressing only an individual opinion derived from limited opportunities of observation.

Rails and Tyres.—The sudden and complete victory of steel over iron as a material for rails—a victory which commenced ten to fifteen years since, and was virtually complete in three or four years from its commencement *—is one of the most remarkable events in the history of engineering. Iron rails had long been found unsatisfactory under heavy wear; and steel rails proved so infinitely superior in this respect, and so free from collateral disadvantages, that once fairly to try them was to adopt them for evermore.

It was not to be wondered at, in view of such a revolution actually accomplished, that there should exist a general expectation that it would be followed by a similar revolution in all other departments of constructive engineering where wrought-iron had hitherto been the material used. Consequently for the last seven years† high metallurgical and engineering authorities have continuously warned us that the universal use of steel, instead of wrought-iron, was immediately imminent in all departments of consumption. Experience however has not altogether justified these predictions; and a little reflection will convince that they were at least premature.

Steel rails have long been produced at as low or at even a lower price than rails ever were of wrought-iron. They can be made of equally good quality by either the Bessemer or the Siemens process, with either acid or basic-lined vessels; and almost any iron ore can now be utilised in their manufacture.

Steel bars, angles, or plates, on the other hand, of the quality required by Lloyd's or by the Board of Trade officials, cost about 46 per cent. more than if of ordinary wrought-iron.‡ Although they can be made from ingots produced by any of the processes referred

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* "Manufacture of Iron and Steel," by Sir Lowthian Bell, p. 379.

† Journal of the Iron and Steel Institute, 1878, p. 436 and following; and also 1881, p. 31.

‡ For this comparison wrought-iron plates are taken at £4 17*s.* 6*d.*, and steel plates at £7 2*s.* 6*d.* per ton.

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to, the ingots as a matter of fact are at present almost exclusively the product of acid-lined open-hearth furnaces. Not much pig-iron enters into their composition, except the purest brands of hæmatite; and the ores whence these are smelted are mainly obtained from foreign countries.*

Again, the qualities required in rails are entirely different from those most needed in constructive material. Rails must of course be tough enough not to break under traffic. Of some, but quite minor importance, is the power to resist corrosion. But the one quality of paramount necessity, the one by virtue of which above all others steel has superseded iron so signally for rails, is the ability to withstand abrasion, disintegration, or crushing, under heavy rolling loads. According to Mr. Price-Williams a steel rail, *cæteris paribus*, will last as long as nine iron ones.† This obviously, and this alone, brought about the great, sudden, and complete revolution in regard to the material to be used thenceforward for this particular purpose.‡

The remarkable anti-abrasion qualities of steel are manifestly of equal value when it is used for tyres; and here also it has consequently almost completely superseded iron. But for the great constructive works for which bars, angles, and plates are so largely used, such for instance as ships, bridges, and boilers, it is obvious that anti-abrasion qualities need not be considered at all. If therefore for these purposes also steel is destined completely to supersede iron, it must be by reason of its superiority in other respects. I now propose to consider wherein it is superior to iron for these other purposes, and to what extent; wherein, if at all, it is inferior to it, and how far this is likely to interfere with its progress;

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* "Manufacture of Iron and Steel," p. 386.

† Journal of the Iron and Steel Institute, 1881, p. 30.

‡ Sir Lowthian Bell, judging from experience obtained on the North Eastern Railway, doubts the correctness of Mr. Price-Williams's estimate, and thinks double is more nearly correct than ninefold. ("Manufacture of Iron and Steel," p. 380). The degree of superiority will no doubt vary with the position, and in direct proportion to the severity of traffic. Under any circumstances the advantage is very considerable.

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and to notice, as we proceed, in what departments of consumption it has as a matter of fact already superseded partially or entirely the older material.

Ship Building.—Steel, as now made to Lloyd's requirements, is superior to iron for ship-building purposes for two reasons, which I am inclined to consider of *primary* importance, namely:—

1st. It is very much more ductile.

2nd. It is equally ductile in both directions of the grain.

To these reasons may be added three others, which I look upon as of *secondary* importance, namely:—

3rd. It has 30 per cent. more tensile strength in the direction of the grain.

4th. It has 50 per cent. more across the grain.

5th. Its elastic limit is 21 per cent. more in either direction of the grain.*

I have placed tensile strength and elastic limit in a secondary position as compared with ductility, because in the former respect iron has always proved itself at least equal to the ordinary demands upon it. Indeed the examples of the "Great Britain" steam-ship, built in 1845, the "John Bowes" in 1851, the "Great Eastern" in 1857, and many others still afloat, prove that, if a well-built iron ship be kept off the ground and free from collisions, its life is practically unlimited. Serious collisions have the same disastrous result, whether iron or steel be the material concerned. The circumstances wherein steel most strikingly shows its practical superiority are when minor accidents occur, such as slight collisions,

* For this estimate I have taken steel (plate) to have 27·3 tons per square inch ultimate tensile strength either way of the grain, and 16·6 tons elastic limit. Iron (plate) I have taken to have an ultimate tensile strength of 21 tons with and 18·2 tons across the grain, and 13·7 tons elastic limit either way. The elastic limit of steel was recently determined for me by Mr. P. C. Gilchrist on a Wicksteed machine, by the average of ten specimens of mild steel tried. The elastic limit of iron is the average of eight specimens tested at the Tees Side Iron and Engine Works, Middlesbrough. There was virtually no difference with and across the grain (see subsequent paragraph on "Bridges and Roofs," p. 319).

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grounding in moderate weather, and so forth. In such cases steel ships have repeatedly remained tight, and returned safe, though in a battered condition: when, had they been of iron, they might probably have become total losses. The benefits of marine salvage however usually accrue to the underwriters, and not to the shipowner. The former have an obvious interest in saving to the utmost, whilst the latter may even gain by the loss of his ship. Apart from humanitarian considerations, no fully-insured owner would wish to recover his ship in a seriously damaged condition. Nevertheless it is the owner who decides the material to be adopted, and not the underwriters. Should the diminution of risk by the use of steel be accurately determined in the future, and the insurance premiums be adjusted accordingly, then it may become the owner's interest more clearly than it is at present to specify the more ductile material.

Up to the end of 1883 steel could not be said to have superseded iron at all in ship-building. For although 166,428 tons of steel shipping were made in that year under Lloyd's survey, still the tonnage of iron shipping surveyed during the same year was 933,774 tons or considerably greater than any previous year. So far therefore the steel used was in addition to and not in replacement of iron.

In the disastrous year 1884 the total tonnage built was 28 per cent. less, whilst the tonnage of steel shipping built was 132,457 tons or 20 per cent. less, and of iron 661,201 tons or 29 per cent. less than the previous year.* Had there been no such material as steel, all would doubtless have been built of iron. We must therefore consider that the proportion of steel shipping to iron shipping built last year is the proportion in which the latter had then become superseded. That proportion is about 20 per cent., or one-fifth. During the first half of 1885 steel vessels amounting to 67,469 tons had been built to Lloyd's survey out of a total of 221,423 tons, or 30 per cent., showing a continued progress in the gradual supersession of iron by steel.

The practical question whether to adopt steel or iron, which shipowners must decide before commencing to build, involves some rather

* Yearly statements of Lloyd's Register of Shipping, 9 Jan. 1884 and 8 Jan. 1885.

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curious considerations. Relying upon the circumstance that 30 per cent. more tensile strength could be obtained in steel than in iron, and with the experience gained by a series of experiments, Lloyd's committee agreed in 1877 to allow for the stronger metal a maximum reduction of 20 per cent. in weight of scantlings, and issued rules accordingly for the general guidance of ship-builders.* A structure built under such conditions might be supposed still to have a margin of 10 per cent. excess of strength. But such reasoning would be misleading, because certain elements which ought to be included in the calculation are omitted. If a piece of metal such as an iron or steel plate be strained as a girder, it gives way by bending when the tensile strain on the outer surface, or the compressive strain on the inner surface, exceeds the respective elastic limits. Power of resistance to compression is therefore of such importance in cases of bending that only in so far as this holds out is tensile strength of any avail. To neglect compression is like attempting to use a lever with a yielding fulcrum.

Again, still looking upon a ship-plate as a broad girder, we shall find that resistance to bending is in proportion to the square of the depth of the girder, that is, the thickness of the plate. For example, if two pieces of plate of equal width and length, and $\frac{5}{8}$ inch and $\frac{1}{2}$ inch thick respectively, be laid upon supports and weights be placed upon them, the first will be found to sustain more than the second in the proportion of 5^2 to 4^2 or 25 to 16. That is, the thinner piece will sustain 36 per cent. less than the thicker one. If the former were steel, and therefore stronger on that account by 30 per cent. than the latter, say of iron, still it would be weaker in the proportion of 30 to 36 by reason of its diminished thickness. It therefore becomes clear that an iron ship is likely to retain its form better than a steel one built 20 per cent. lighter.

It is but just to Lloyd's committee to point out that, whilst permitting a reduction of thickness of 20 per cent. in steel ships, they insisted on, and have invariably enforced, a system of testing and inspection far more severe and rigid than was ever applied to iron

* Journal of the Iron and Steel Institute, 1878, p. 435.

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ships. All the steel used must support a tensile strain of between 27 and 31 tons per square inch in any direction, besides a quenching test (p. 335). And whatever does not fulfil these conditions by ever so little is relentlessly rejected. The sudden transition from the comparatively easy-going inspection which iron for ship-building receives, to the severity of that of steel, is of itself suggestive that Lloyd's committee have for long been themselves apprehensive that 20 per cent. is far too great a reduction to allow. They seem in fact to say to the ship-owner:—"If you *will* avail yourself to the utmost of our permission to reduce thicknesses, in order to cheapen the cost of the ship and carry somewhat heavier cargoes, you may do so. But we will watch that not a piece of steel is used which has not the very highest degree of tenacity attainable, short of liability to brittleness."

During the last seven or eight years evidence has not been wanting to confirm the suspicion that the 20 per cent. reduction was too great even as a maximum. It is not easy to obtain exact particulars or definite cases, inasmuch as those who are best informed naturally refrain from proclaiming what might tend to depreciate their own work or their own property. But I am informed on authority which I have no reason to doubt that there have been cases of steel ships returning from voyages more or less strained and out of shape, in a way rarely experienced previously; other cases where it has been found necessary to strengthen the ship internally after completion, in order to avert anticipated difficulties of the same kind; and one case where the position of each frame inside could be traced by the eye from the outside, owing to the plates bulging inwards from external pressure.*

It will be readily admitted by all who have ever come in contact with Lloyd's committee or their surveyors that their operations are habitually conducted in a thoroughly able and conscientious way. Otherwise they would never have attained the commanding position in public estimation which they now enjoy. Equally will it be conceded by all, including themselves, that their policy ought never

* See article on Steel Ships in "The Engineer," 17 April 1885, page 303.

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to be such as to cripple or retard the use of the most suitable materials in the best possible way. Their rules and practice should surely be sufficiently elastic to allow every material to find its best application, and every kind of ship and every part of a ship to be made of the material most appropriate to it.

At present however there are materials eminently suitable for ship-building, and far superior to iron, which are virtually excluded, because they do not coincide with the formula for steel intended to be used in reduced thicknesses. I allude to steel made by the Bessemer basic process; but the same remarks will probably apply where converters of the Clapp-Griffiths type are used. Bessemer basic steel comes up to and indeed considerably exceeds Lloyd's requirements, with certainty and regularity in every respect but one. That one is the tensile test. Instead of standing 27 to 31 tons per square inch for all thicknesses, it stands from 24 to 28 tons. Now if Lloyd's committee would permit such steel to be used, provided the scantlings were thickened proportionately, there would be no ground for complaint. But as the matter stands now, an owner could not have a vessel classed at Lloyd's, if built of steel milder than corresponds with 27 tons per square inch. This is true even though he chose to make the steel as thick as if it were iron, and even though such a ship would obviously be better than an iron one, and probably better also than one of steel of the thinnest scantlings allowed.

The question will appear the more serious when we recollect that the basic process is the only means by which five-sixths of the ore of this or any other country can be utilised at all for steel-making. Nature has endowed us with a great abundance of native iron ore, most of which is now available for making steel suitable for ship-building. Nevertheless we seem to prefer to import from Spain and elsewhere, and to neglect our own inheritance. Most of the splendid steel ships afloat are in this sense derived from foreign material, the further supply of which might be stopped at any time by war or caprice. Surely this cannot be looked upon as a final or very stable arrangement. At all events Lloyd's committee ought scarcely to favour foreign in preference to British produce, unless

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compelled by reasons more cogent than any which appear at present to exist.

Bridges and Roofs.—We have seen that the physical qualities requisite in a material for rails and tyres are widely different from those necessary in a material for ship-building. This however does not preclude the possibility that one material of versatile character should cover the whole ground, and be best for both. Next to railways and ships, perhaps bridges and roofs have hitherto absorbed more wrought-iron than any other kind of constructive work.

Here again a little thought will convince us that the order and degree in which the qualities of the material are essential must be altered. I am inclined to place in the rank of *primary* importance: —1st, High elastic limits under tension and compression in one direction; and 2nd, Non-liability to corrosion under atmospheric conditions. And of *secondary* importance:—3rd, Ultimate tensile strength; and 4th, Ductility.

In bridges and roofs it is clear that the material must never be strained beyond its elastic limits, tension and compression being equally taken into account. Otherwise the form of the structure would alter, and disintegration commence; and time would bring total failure. The margin between the maximum working strain and the elastic limits is therefore the real margin of safety; and whatever reduction of area takes place by corrosion narrows this margin of safety. It is probable that all iron and steel roofs and bridges will, unless previously removed, ultimately become unsafe in this way. Ignoring great disasters, which can never be perfectly provided against, the further margin between the elastic limit and the ultimate strength, either in tension or in compression, is never made use of at all in bridges or roofs that are sufficiently strong, there being no current liability to abnormal strains, collisions, bulging, and so forth, as there is in the case of ships. These secondary qualities are therefore only of use as signs of reliability within the elastic limits—in short as evidence that the material is not brittle.

The comparative rarity with which elastic limits are mentioned in specifications for bridge-building materials, and, when they are so

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mentioned, the lowness of the limits named, seem to indicate that the view above set forth differs from that hitherto commonly entertained, and that the elastic limit attainable, especially in the case of iron, is not widely known. A series of experiments made some time since at the Tees Side Iron and Engine Works proved that the elastic limit in tension of ordinary Cleveland iron bridge-plates $\frac{3}{8}$ inch to $\frac{1}{2}$ inch thick is 13·7 tons per square inch. The ultimate tensile strength ascertained at the same time was 21 tons with and 18·2 tons across the grain; and the extension in 8 inches length was 7½ per cent. with, and 3 per cent. across.

A curious and important fact, though little known, is that the elastic limit in iron plates is equal in either direction, as it is in steel, although the ultimate strength and ductility are inferior in the cross direction.*

On account of the greater cheapness of iron, and perhaps for other reasons, the use of steel has not yet made much headway in this country as a material for bridges and roofs, except where very long spans are required. In such exceptional cases the weight of the structure itself is by far the greatest source of strain; and therefore it becomes imperative to use a material which affords a high elastic limit in proportion to its weight. In certain other countries, notably America, the practice is somewhat different, steel being relatively more in use. But there, no cheap finished iron is obtainable, as here; and their rivers being larger, there is more demand for wide spans.

Boilers.—Next in importance to the specialities already discussed, steam boilers may perhaps be classed. Apart from the question of corrosion and certain minor difficulties which I shall hereafter refer to, it is hard to find any respect in which mild steel is not better than iron for boilers. Moreover it is not here under any disadvantage as regards original cost. Iron boilers have always been made of

* It seems clear that mild steel has much less practical advantage over wrought-iron when used for bridges and roofs than when used for ships. (See previous paragraph on "Ship Building," page 313, and foot-note.)

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special qualities, which on the average cost as much as modern steel. Indeed in those cases, and they are many, where the highest South Yorkshire brands have habitually been specified, steel with far superior capabilities is obtainable at a much lower price. Can we wonder that marine boilers are now scarcely ever built of iron? The very material, weight for weight, costs less than formerly. To this advantage must be added the gain of displacement, if they be made thinner in proportion to tensile strength; or, which is of more importance, the extra steam-pressure carried if the full thickness be retained. To obtain adequate furnace-room and heating surface, marine boilers must be of large diameter; and to withstand the ever increasing pressures needed for multiple expansion, the thickness and tenacity of boiler shells must be the utmost consistent with safety. These requirements, with the large areas and heavy weights which they involve, are more easily met by steel than by iron. As in the case of steel for ship-building, the insistence by Lloyd's and by the Board of Trade surveyors on a very high tensile strain, without relaxation for the greater thicknesses, has led to certain difficulties and dangers. No one is more alive to these than Mr. W. Parker, chief engineer surveyor to Lloyd's; and in his hands any modification of rules, suggested by experience, may safely be left.

Engineers and surveyors generally must recognise that greater thicknesses, whether in steel or iron, involve less work upon the material; and less work means less tenacity. This ought to be understood, accepted, and allowed for. Otherwise the manufacturer is compelled to increase the amount of carbon in his steel in proportion to thickness, and perhaps beyond safe limits; and thus are incurred the risks of such disastrous failures as have occasionally taken place.

For boilers other than marine the supersession of iron by steel has not been nearly so rapid, nor is it at all complete. In Lancashire, where large diameters are in vogue, and where Mr. Adamson and other able engineers have long advocated and set the example of using steel, it is now largely employed. But throughout the country generally the older material is still mostly preferred, at all events for shells. For difficult work, such as

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flanged tubes and double-flanged end-plates, the diminished proportion of wasters attending the use of steel is rapidly leading to its extended adoption.

Rolling Stock.—Iron or steel under-frames for rolling stock are much commoner on Continental than on English railways. A metallic framework is always more permanent and satisfactory, and usually lighter than a timber one of equal strength. But experience has shown that the latter material does well enough; and in case of collision the débris is more easily dealt with by splitting up and burning. A crumpled-up iron or steel under-frame is an exceedingly awkward thing either to handle, or to remove, or to annihilate. It must however be borne in mind that, as in the case of ships, it is impossible so to construct fabrics that they shall withstand serious collisions without inconvenience; and the possibility of abnormal occurrences should not be allowed to handicap normal use.

On the North Eastern Railway excellent hopper mineral wagons made entirely of iron have been in use for fifteen or twenty years, and apparently with satisfactory results. Recently a large number have been built at Darlington of basic steel, for West Coast traffic. A saving of weight has thereby been obtained, and increased power to resist damage from tipping the minerals in and hammering the sides by the workmen to shake them out.

Railway Sleepers.—A still more important use for iron or steel in the future is, or should be, for railway sleepers. Here again some foreign and colonial railways are in advance of our own: for iron sleepers have been in successful use abroad at least fifteen years. A large number on Mr. James Livesey's plan have been manufactured at Glasgow and at Middlesbrough; but as far as I know none of these were for English lines. On the North Eastern Railway, a few years since, about a mile of line was laid down upon Mr. Charles Wood's system, with promising results except in one particular. Mr. Wood's peculiar clip-fastening necessitated cutting two large square holes just at the part where the sleeper was subjected to most strain; and failure occurred after a time by

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rupture through or near these holes. The weak points of Mr. Wood's system are corrected in Mr. F. W. Webb's sleepers; and a promising experiment with these, or with a slight modification of them, is now in progress near Middlesbrough. Iron or steel sleepers with proper fastenings, and of such a form that the weight of passing loads is well distributed over them, are as elastic as wooden ones, and far more enduring. But for their extra initial cost, there seems to be no impediment whatever to their general adoption. They can be used equally well with hard or soft ballast, and with flanged or double-headed rails. Wooden sleepers no doubt also answer their purpose perfectly, so long as they remain sound. But the conditions to which they are subject are extremely unfavourable to endurance: especially under the chairs and at the spike-holes, where endurance is most essential. At these parts moisture is continually entering through capillarity, and then evaporating. This action alternating with the weather, and accompanied by severe vibration with every passing load, is highly conducive to premature decay. Some railway companies use their old sleepers for fencing purposes. They put them vertically side by side with one end buried in the ground, the other ends being bound together with hoop iron. An excellent fence is the result, until the buried ends have rotted away, which must occur before long. An inspection of such a fence is not a little interesting and instructive to an engineer. The way in which the chairs are found to have imbedded themselves into the solid timber to a depth varying from $\frac{1}{4}$ inch to $2\frac{1}{2}$ inches is very remarkable. The spike-holes are usually greatly enlarged, and the wood unsound all round. The average time when sleepers arrive at this condition is said to be about nine years. It seems a great pity that timber imported only a few years since, and still for the most part sound, should have become useless for its original purpose because a small but essential portion has decayed. And for the secondary purpose of fencing, it must for the same reason be used of five or six times the thickness which would be required in new and sound planking. Considering the growing scarcity of timber all over the world, together with the ever increasing need for it, we ought surely to look with jealousy upon its continued use in such enormous

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quantities for sleepers, where metal would better answer the purpose. It is a form of waste which should be reprehended in the public interest, just as should the use of coal for ballasting or other obviously wasteful purpose. The same timber which becomes useless for sleepers in say nine years would last at least a century in the roof or flooring of a house. Piles of Baltic timber driven twenty-two years since, and always immersed in water, I lately examined, and found still perfectly sound. Had they been used as sleepers, they would have needed replacement twice already.

There is also another cogent argument against the continued use of timber sleepers. Each one delivered by a foreign ship at a British port costs a certain sum of money, representing the foreign labour of all kinds expended in producing and delivering it. If from Sweden, and worth 3*s.* 8*d.* each,* then every six purchased per week would represent 22*s.* per week, or sufficient to support a Swedish family. Suppose iron or steel sleepers costing 7*s.* 4*d.* each were substituted, then every three of these purchased per week would represent 22*s.*, or say equivalent to an English family maintained. Estimating British railways at 30,000 miles of single line, and the sleepers at one yard apart, we shall find that the number in use is 52,800,000. If these were of iron or steel, and required replacement at the rate of 1 in 18 per annum, then 2,933,333 would be required per year, or 56,410 per week. These represent a weekly expenditure of £20,680, which would maintain 18,800 British families, or say a population of 94,000 persons. The question arises whether railway companies, being in some measure in the position of public trustees, should not take such things into consideration. An extra £20,680 per week spent among the British industrial classes would be most acceptable to them at present; and as the railway companies would also be benefited by increased endurance, and diminished labour, superintendence, and risk, there would be a gain all round. The above estimate however has reference only to maintenance, after metallic sleepers have taken the place of wooden ones throughout

* See Mr. W. J. Cudworth's remark in the Proceedings of the Cleveland Institution of Engineers, 9 June 1879, p. 211.

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the country. It is obvious that of far greater present importance to British industry would be the demand due to first substitution. The magnitude of the trade in metallic sleepers, which is likely to arise before long, is difficult to realise. It will be nearly as important as the rail trade. After so many years of depression, British engineers may perhaps be excused if they strain their eyes a little in the directions in which relief may and ought to come. Our foreign competitors are everywhere building up and maintaining by artificial tariffs exotic industries which could not otherwise endure for a twelvemonth. Though sufferers by this their policy, we should not wish to imitate it. We should, on the other hand, fix our own national commercial policy on such sound economic principles that our trade may not be precarious, nor our prosperity, when it comes, unstable. But without violating economic principles, and indeed in obedience to them, may we not fairly ask that the orders of our great public companies should be given to British rather than to foreign producers, in all cases like the present, where no disadvantage is entailed upon the purchasers; and that opportunity to earn a livelihood should, like charity, begin at home?

Bar Iron.—Whilst rolled steel is gradually taking the place of rolled iron in so many directions, there is one in which it seems as yet to have made little or no progress; and that is in competition with ordinary bar-iron. Makers of this speciality agree in saying that only a very small percentage of their output is as yet of steel, although they are equally willing and able to supply either material. Inasmuch as bar-iron is the form in which country blacksmiths and rural implement-makers, whether British or foreign, buy most of their material, this is perhaps no more than might have been anticipated. Such consumers have their traditions and their habits, and are slow to change them. Steel they find harder to work, more difficult to weld, and requiring more care to smith. Above all it is still substantially dearer. These things are naturally regarded as impediments in country districts, and the superior physical properties of steel are there scarcely appreciated. The blacksmith's customers also are not of the kind to make or enforce rigid specifications; and

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so the use of bar-iron goes on, and is likely to go on, perhaps for generations.

It might have been expected that such extensive consumers of bars as leading makers of agricultural implements would by this time have been found using steel in quantity. But it does not appear that this is so. Occasionally and for special purposes, such for instance as for the wearing surfaces of sledges, steel is used; but not generally. Even for the tyres of cart-wheels iron is preferred, because it is more easily welded. An argument is often used which has great weight. It is urged that wherever implements may be *made*, they will sooner or later come to be *repaired* by the country blacksmith; and that therefore the material and construction adopted by the original manufacturer ought to be within compass of the ideas and resources of the rural repairer.

Rolled Joists.—Until lately this speciality was almost entirely monopolised by the Belgians. Now large quantities of rolled joists are produced at Middlesbrough. There appears to be no advantage in making them of steel, as in this material they are more difficult to get sound at the edges, less easy to straighten, and generally more costly to produce. And if made thinner than the ordinary sections for iron, in order to reduce their cost in steel, they are deficient in stiffness. It is note-worthy that, at their present market price of £4 2*s.* free on board at Antwerp, rolled joists are the cheapest form in which finished iron of any kind is or perhaps ever has been produced.

Castings. — Steel castings began to come into extensive use about twenty-three years since. They were then made of crucible steel only, and no great size or weight was attempted. An urgent need had long existed for a material which could be cast in a mould, and which should yet have the toughness and tenacity of wrought-iron. Portions of machinery that are subjected to severe strain, such for instance as the pinions and clutches of reversing rolling-mills and the propelling gearing of steam-plough engines, are cases in point. No increase of substance would give the requisite

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strength so long as the material remained cast-iron; inasmuch as the destructive force depending on the inertia of the parts would increase proportionately. But the difficulty was entirely obviated by the use of steel castings; for the strength and toughness are then largely increased without increasing the inertia. Before the time named, articles of enormous weight, such as screw-propellers, were occasionally made even of cast brass or gun-metal, at a twelve-fold expense compared with cast-iron, in the hope of obtaining a slight increase of tenacity and some little ductility. The modern alloys of manganese, and phosphor-bronze, and Dick's metal, which in some forms are claimed to be as strong and tough as wrought-iron, were then unknown; and therefore the need of a better material for castings was more urgent than it would otherwise have been.

The cost of steel castings has been greatly cheapened latterly by the employment of the Bessemer and open-hearth processes. But the expectation which is occasionally expressed, that steel castings are about to supersede iron ones altogether, does not seem at all likely to be realised. For, in the first place, steel castings are from three to five times dearer than iron ones; and in the second place, whilst their general superiority is beyond question, iron castings have still the advantage in certain respects.

Steel castings are dearer than iron:—1st, because the value of molten steel is considerably greater than that of molten cast-iron; 2nd, because, in order to get sound castings, there must be very much more waste in "dead-heads" with steel than with iron; these are difficult and costly to remove, and entail a loss represented by the difference between steel-casting value and pig-iron, which is greater than that between iron-casting value and pig-iron; 3rd, because the annealing process, without which steel castings are useless, is tedious and expensive; 4th, because the higher melting point of steel compared with iron necessitates more costly moulds. In consequence of these peculiarities the quantity of finished steel castings capable of being turned out in a given space, with a given number of hands and a given value of plant, is small compared with a corresponding output in iron castings. And as these impediments are mostly of a

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permanent character, the relative value of steel castings is not likely to be greatly altered in the near future.

As to those respects in which iron castings have the advantage:—1st, steel castings seldom if ever have the fine surface, sharp edges, and pleasing appearance of good iron ones. This arises no doubt from the higher temperature of the molten metal in the former case, and its destructive action on the surfaces of the mould. Annealing also usually detracts considerably from the appearance. 2nd, both on the surface and internally steel castings are much more liable to cavities and blow-holes. 3rd, if not fully and equally annealed throughout, steel castings are quite unreliable and even treacherous. 4th, the delay in obtaining steel castings, owing to the time required for annealing, is so considerable as often, in pressing cases, to compel the reluctant substitution of iron ones. Besides the points just raised, there are many others which seem to force us to the conclusion that the art of iron founding is in no danger of extinction, or even of serious diminution. In a majority of the cases where cast-iron has hitherto been used, mass, and the stiffness due thereto, are required, rather than great tenacity or ductility. For columns, water and gas mains, engine frames, cylinders, condensers, bed-plates, lathe beds, machine frames, bridge cylinders, railway chairs, household grates, roofing gutters, rain pipes, certain culinary utensils, cellar gratings, and for very many other purposes, steel would not answer better, if indeed so well as iron, even though there were no difference in price.

Again, for wearing surfaces, such as the motion blocks and bars of a steam engine, nothing works better than cast-iron upon cast-iron, if only the areas be sufficient; and this property is still more remarkable in the case of pistons in cylinders and slides on slide-faces, working as they often do for long periods, and remaining in excellent condition, with no other lubrication than the steam itself. There is not, so far as I am aware, any evidence to show that steel castings would answer at all in such positions. There are indeed purposes for which the one material is fittest, and others for which the other is fittest. Time will show; but meanwhile nothing like the wholesale superseding of cast iron by steel is in the least probable.

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Forgings.—Concurrently with steel castings, steel forgings have gradually been coming more and more into general use. For very fine and delicate work, such as the spindles and pinions of watches and clocks, high-carbon crucible cast-steel has been used for an indefinite period, and long before the days of Bessemer or Siemens. Cost is nothing, homogeneity everything in such cases; and capacity to harden is scarcely less valuable. A streak of cinder, of little moment in a large forging, might render a very small one weak at a vital point.

Modern mechanisms tend more and more to comprise complicated parts machined into form out of solid forged lumps by a number of successive operations. A finished piece of this kind has perhaps slender projections, whereof the soundness and strength are essential. The only way to make a forging of wrought-iron suitable for such a purpose is so to work it that the grain of the iron shall follow each projection, as the woody fibres do in the stem and branches of a tree. This desideratum however is always difficult, and in complicated forms impossible to obtain. But steel has practically no grain, and is as strong in any one direction as in any other. Thus it is eminently suitable for such work, and is naturally superseding iron completely. A good example is afforded by the spherical sector-pieces with shafts, forming the two principal revolving parts of the "Tower" engine, which were exhibited and described at a recent meeting of the Institution by Mr. R. H. Heenan. Several parts of the locks of rifles and machine-guns, and of the breech-closing and discharging apparatus of heavy ordnance, are also cases in point. In making steel forgings the smith now starts with cogged blooms, purchasable of any desired weight. These are simply ingots rolled down to a rectangular section and sheared off to a given length. They are the cheapest form in which wrought steel can be purchased. Indeed the trade in soft steel blooms for miscellaneous purposes has lately increased at a surprising rate. Mr. Arthur Cooper, of the North Eastern Steel Works, Middlesbrough, tells me that about 900 tons per week is his present output of basic-steel blooms and billets, and exclusive of rails. Half of this is used for wire-making, and the other half for tin-plates, stamping-sheets, tube-strips, boiler-plates, angles, forgings, nails, locks, hoops, and sleepers.

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With regard to gun and rifle barrels, a complete revolution has taken place within the last few years. The system of coiling and then welding wrought-iron strips to form a barrel has virtually passed away; and solid steel, rolled from the ingot, and then drilled through from either end, is the system which now prevails both here and abroad. A similar change has taken place with respect to heavy ordnance. The imposing operations of coiling wrought-iron bars of large section and enormous length, and then welding them under a colossal steam-hammer, are no longer to be seen at Woolwich. Every part of every piece of ordnance is now made of steel, and all guns are breech-loading. This revolution has only taken place within the last three years, the decision having been arrived at on Colonel Maitland's recommendation, after he had visited various foreign works and arsenals, and satisfied himself that there could no longer be any doubt as to the absolute necessity of the change.

But there are certain specialities within the general class of forgings, with respect to which it is by no means yet clear that steel is superior to wrought-iron. I refer to heavy shafting, axles, and especially locomotive crank-axles. Let us consider the last first.

No one can view an express train dash by at full speed without feeling that the passengers are, as it were, "carrying their lives in their hands." The train is made up of a great number of parts, all of which are liable to breakage; and of some the failure would inevitably lead to terrible disaster. In this sense, perhaps the most important detail in a train is the crank-axle of the locomotive. There are many and diverse opinions among engineers as to crank-axles. Some prefer them of iron, some of steel; and some think they should be avoided altogether by the adoption of outside cylinders. On several of our leading lines, and notably on the Great Northern, express engines have now plain axles throughout.

But on other lines crank-axles are used in all types of engines; and on all lines they are used in some types which are liable to be run at considerable speed. When last November, by the kindness of Mr. S. W. Johnson, our Members were shown through the engine-building shops of the Midland Railway at Derby, nothing to which their attention was drawn was of greater interest than the

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elaborate precautions taken to prevent the breakage of crank-axles, in the crank-pins and upper end of the crank-cheeks, where they usually give way; and to secure that, in case of fracture, they shall at all events hold together until the train can be stopped, or a station reached. Each cheek of each crank is hooped, and each crank-pin has a bolt passing right through. All this is no doubt wise and commendable, and will prevent a certain number of disasters. But the very earnestness of the efforts to meet the danger is obviously a recognition of its existence; and so it tends to augment as much as to allay the prevalent apprehension that crank-axles in locomotives are, after all, dangerous things.

The Board of Trade returns for 1884 * confirm this view in a very remarkable manner, and show also beyond a doubt that thus far steel in crank-axles is *less* reliable than iron. During last year 385 axles of all kinds failed, involving death to 24 and injury to 73 persons. Of the 385 failures, 200, or 52 per cent., were locomotive crank or driving axles. The average mileage of the iron crank-axles was 216,333 miles, and of the steel ones 173,287 miles, or 20 per cent. *less*. The question arises:—if crank-axles cannot be altogether avoided in locomotives, how can they be strengthened at their known weak points?

The distance between the wheels of a locomotive is fixed by the gauge of the rails. Between them, and within the main bearings, must come the two cranks; and these must be a certain distance apart to suit the cylinders and slide-chest. Deep cranks, with cheeks of limited thickness thus involved by the exigencies of the situation, cannot be *bent* into form, as would be otherwise preferable; and there is no alternative but to cut them out of the solid. No fibre can be developed round the crank during forging; and therefore (at all events in the case of iron) the metal at and near the crank-pins is naturally less reliable than in the straight portions of the axle.

The obvious way to compensate for inferiority of quality is to add to quantity. This cannot be done in width across the crank, for

* Returns of Accidents and Casualties reported to the Board of Trade during 1884. (Eyre and Spottiswoode. London.)

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reasons already named; but there is nothing to prevent increase of depth—through the crank. Judging from recently published drawings of locomotives, crank-pins appear to be habitually made only a trifle larger in diameter than the plain parts of crank-axles. Now if the strain on the crank-pin were merely a shearing strain, or a short bending strain, as it is on the crank-pin of an outside-cylinder engine, this would be more than enough. But it is not so. In running round a curve, one driving wheel goes faster, and the other slower, than they should to *roll* on their respective rails. The whole force of adhesion acts on the tyre of one wheel in one direction, and the other in the other, tending with the leverage of the radius of the wheel to twist the axle. If there were bearings close to each cheek of each crank, there would then be only a shearing strain on the crank-pins; but as it is, the axle springs at the gaps, until the twisting strain on the pins is equal to that on the plain parts.

The same thing occurs alternately when each piston, being at half-stroke and therefore making maximum rotary effort, is driving the opposite side wheel *through* the opposite side crank-pin, which is then on the centre.

Another strain to which locomotive crank-axles are liable is the nipping strain arising from the side-to-side oscillations of the engine. It is clear that these indeterminate strains, alternately closing and opening the gaps, tend to break the cheeks at a point just below the pin.

It thus appears that the crank-pins of a locomotive crank-axle are subjected to torsion strains equal to those on any other part of the axle. They are also subject to diminution by wear, and are under the disadvantage of being hidden from inspection by the connecting-rod ends when at work. The crank cheeks at their outer ends are subject to greater strains than elsewhere; and at these severely strained places the metal for want of sufficient work and of a right kind during construction is likely to be inferior. We might therefore expect *a priori* that failures would mostly occur at these places. And such is the fact.

The obvious remedy appears to me to be to make the crank-pins, not about the same size, but very considerably larger than the rest of the axle, and to deepen the crank cheeks to suit. The crank,

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comprising the pin and cheeks, would thus be formed on the principle of a cramp or punching bear, in the sense that the material would be most thickly accumulated round the deepest part of the gap. The increased revolving weights could be easily balanced on the wheels, and the boiler raised if more clearance were required. Cheek-straps and through-bolts could still be added as a precaution. Such a change would, I feel sure, largely augment the average life of locomotive crank-axles, and increase the general confidence in their reliability.

As to heavy shafting, it is still an open question whether steel or iron is best. The preponderance of opinion among forge-masters in the North is, I think, decidedly in favour of iron. The price also is substantially lower. It is said that a steel shaft, having a slight nick or fault across a journal, will break or tear right through when strained; whereas an iron one, being built up in layers, usually remains unaffected beyond the immediate locality of the fault.

Mr. A. C. Hill, President of the Cleveland Institution of Engineers, informs me he has been compelled to abandon the use of steel crank-pins in his shunting engines, because they so frequently broke short off; and he has obviated the difficulty by using Low-Moor iron. This agrees with my own experience in all cases where there is heavy strain with shock. I have repeatedly tried soft steel, containing under 0·1 per cent. of carbon, for the wearing faces of the clutches of reversing rolling-mills; also for bolts uniting the two halves of a heavy clutch. In both cases steel had to be abandoned, the greatest reliability and endurance being obtained from iron forged from piles of carefully selected bar and scrap.

Most users and makers of steam-hammer piston-rods also advocate iron. They say it is less likely to break, and moreover can be repaired by welding when it does give way. Some forge-masters are now habitually making forgings of steel scrap. But they are obliged to work within a much narrower range of temperature than in the case of iron; and there is a greater risk of flaws from imperfect welds. Others prefer half steel and half iron scrap. The formation of the requisite cinder for protecting the surfaces during welding is assisted by the use of a flux of silica and lime. Hammer-rods

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however, made in this way, cannot be so easily repaired as those made of wrought-iron. Whether they be of iron or of steel, hammer-rods always give way eventually. Their duration is no doubt largely influenced by the mode of attachment to the head, a certain amount of freedom being very advantageous. Where this point is attended to, my own experience is that good results may be obtained from steel. For heavy shafting I have had about an equal proportion of failures in steel and in iron.

Homogeneity and Tearing.—The superior tensile strength and ductility of steel as compared with wrought-iron, and its independence in these respects of the direction of fibre or grain, arise from its purity and homogeneity. The molecules composing it, when it is in a fully wrought condition, seem to be in almost absolute contact in every direction. There is no appreciable interposition of cinder or other foreign substance, and they are therefore fully subject to cohesive attraction.

But this homogeneity is the cause of extreme susceptibility to tearing strains. Imagine for a moment a piece of steel plate to be composed of a number of molecular columns, side by side, each column being equivalent in height to the thickness of the plate. Let us now apply a splitting force just capable of overcoming the lateral cohesion of two contiguous columns forming the edge of the plate at a particular place. They are separated, and offer no further resistance; and the force is available to act on the next pair of columns. These separate, and the split proceeds. The view that mysterious cracks in steel are all in the nature of *tears*, seems to be confirmed by the fact that in such cases there is never any appearance of contraction at the fractured edges, notwithstanding the general ductility of the metal. This also may, I think, be explained. Let us suppose that one pair of molecular columns in the line of a crack came in its turn under the separating strain, and tended to shorten before parting company. It is evident that the pair of columns last torn apart and now free from strain, and the next pair ahead not yet strained, would both act as props, and afford support, so as to prevent shortening of the then strained

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pair. In this they would be assisted by all other contiguous columns; whereas if the whole piece of plate were strained equally across while being pulled in two in a testing machine, each molecular column across the line of fracture would be under identical conditions, and none would interfere with the tendency in its neighbours to shorten. Cracks in soft steel plates, unaccompanied by contraction at the fractured edges, must then of necessity be tears; and tears cannot show evidences of contraction.

A wrought-iron plate is not liable to tears of this kind, because possibly the cinder which permeates it acts as a sort of padding between the molecular columns. Suppose a similar strain to be applied to the edge of an iron plate, and to leave the first pair of columns separated and just beyond the range of cohesion. If we were dealing with steel, the next pair of columns would now be sustaining the full brunt of the force. But iron being the material concerned, there would be a padding of cinder intervening, and the next pair (or possibly group) of columns would be some distance off. The gap commenced would have to be widened or wedged out, as it were, before the second row or group was strained beyond cohesion; and for this the *range* of the original force would perhaps be insufficient.

To put the case another way. A very finely woven muslin fabric may easily be *rent* across. But if the threads composing it were re-arranged so as to form a coarse net, it would no longer be easily *torn*, though its combined tensile strength would be unaffected.

Mr. Baker, in the course of the paper he read before the British Association at Montreal last autumn, said that alarm had been created at the Forth Bridge works by a certain Landore steel plate $1\frac{1}{8}$ inch thick, which broke like cast-iron on being bent cold to the flat radius of 6 feet. He was certain it was not the fault of the material, as a shearing from it had been bent round to a radius of $1\frac{1}{2}$ inch after being made red hot and cooled in water. He afterwards traced it to the damage locally commenced by shearing. This could not have extended more than $\frac{1}{16}$ inch from the edge, because planing removed it. Yet it affected the entire width; for the plate 4 ft. 6 ins. wide snapped across as easily as a strip 1 inch wide. The difficulty

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was equally removed by annealing. His practical conclusions were to the effect that the strains initiated by shearing or punching might be fatal to any steel plate, unless removed by planing or rimering, or by annealing.

Some time since, a number of steel test-pieces were laid on the table of an office adjoining mine, which had all successfully undergone Lloyd's quenching test. That is, each piece had been heated red hot, then plunged into water at 82° Fahr., and then when cold bent round double, the inner radius of the curve being $1\frac{1}{2}$ times the thickness of the plate. Several times during the next few days sharp reports like those of a small pistol were heard proceeding from the office. The cause was not immediately detected; but it was afterwards accidentally discovered that some of the test pieces had developed fine cracks across the outer surface of the bend. Although quite sound at first, they had evidently been under severe strain, and their tuning-fork form had caused the sharp report when they gave way. There was no sign whatever of contraction along the fractured edges.

Smith Work.—Within a certain range of temperature steel can be more successfully worked than iron; but that range is narrower. Thus at the temperature familiarly known as cherry-red, a good steel plate can be bent double, and then redoubled cross-wise. An iron boiler-plate is considered good if it bends double with the fibre, and to a right angle across, at a full red heat.

Steel plates are best worked at a low heat, iron ones at a somewhat higher heat. At a welding heat steel plates require the utmost care to avoid burning or fusing, after which they become quite brittle. A number of steel plates which I saw lately being dished hot to a very awkward form, between two dies under a steam hammer, were mostly failing. The men were advised to lower the temperature to cherry-red, and the remaining plates all stood the test.

Steel is less easily welded than iron. Thus the blow-holes, or piping, which occasionally occur in ingots, are never welded up in subsequent rolling. They become enlarged, and are the cause of the lamination which is not infrequently found in steel plates. Mr.

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Adamson, in the course of his paper read at Paris in 1878,* gave it as his experience that some steel could be welded, but not all. He believed that for this purpose the carbon contained should not exceed 0·125 per cent. It is still true that all steel will not weld with ease and certainty; and it is not yet quite clear wherein the difference lies.

It must not be forgotten that there are welds and welds. A good weld is one where the welded pieces will afterwards bear the same cold bending through the weld as through the neighbouring solid part. Probably there are very few welds, though to all appearance perfect, which would stand this test. As an instance of good practice in welding steel, I may mention that at Messrs. R. and W. Hawthorn's works at St. Peter's, Newcastle, marine boiler flues, 7 feet long, are soundly welded at one heat. A V groove joint, carefully planed out, is adopted; and certain fluxes are used to fuse the scale, which would otherwise prevent adhesion of the surfaces.

Flue rings, conical tubes, and other details of boiler work, involving welding and subsequent flanging, can now be made of suitable steel almost as easily as of iron; and when made, they are incomparably better. For to make a welded and flanged tube of iron not more than $\frac{5}{16}$ inch thick, a very high quality of iron must be used; and even then the tube will be found unable to stand subsequent rough usage, such as setting cold to suit deviations in the dimensions of the flues. The repeated heatings undergone during welding and flanging have indeed taken the "nature" out of the iron, and left it brittle. But steel tubes when finished and annealed will stand battering about cold, without any fear whatever of damage.

Let us now consider for a moment the behaviour of steel at higher than atmospheric, but yet non-luminous, temperatures. Iron plates will bend with the grain to certain moderate angles, inversely proportionate to their thickness. Across grain they will bend much less. If however they be heated, their bending capacity is improved more and more up to a full red heat. In making iron masts and yards for ships, it is necessary to bend the plates across grain to a

* Journal of the Iron and Steel Institute, 1878, pp. 395-6.

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rather quick curve. On account of the great length and small breadth of such plates, it is impossible to develop much fibre by rolling in a cross direction; and consequently, if bent cold, longitudinal cracks are apt to appear. But if heated to a very moderate extent they will bend easily. So in closing seams in iron boilers, it is customary to warm the parts to be closed by heaters, and then beat in with heavy hammers. In setting studs or straightening anything accidentally bent, the application of a little heat has always been found, in the case of iron, to make easy and safe what would otherwise be difficult and risky.

Now steel appears to differ entirely from iron in this respect. If five pieces be cut from a steel plate and tested in different ways, it will be found that:—the first may be bent nearly double cold; the second may be doubled and redoubled at a cherry-red heat; the third will successfully undergo Lloyd's quenching test (p. 335). If the fourth be then filed bright on the edges, and held over a smith's fire until the bright edges turn blue or straw colour, and it be then bent, it will probably be found to break short at about a right angle, the colour of the fracture being the same as of the edges, and it will have all the appearance of brittleness. If the fifth piece be heated red-hot, and then slowly cooled until the edges, which must be kept bright, turn blue or straw colour, the same brittleness as in the last case will probably be found, though not quite to the same extent.

Attention was called to this unreliability of steel at a non-luminous heat, by Mr. Adamson in the paper already referred to; and since then the facts have been confirmed by experiments made in this country and in America, though no explanation of the phenomenon has to my knowledge ever been given. Mr. Ephraim Jones, of Middlesbrough, who rolls sheet steel, informs me that down to $\frac{5}{16}$ inch and $\frac{1}{4}$ inch thickness he has experienced no trouble from brittleness. Nor has he with the very thin gauges, which he always anneals. But with the intermediate gauges, which were finished at a black heat, he had great trouble until he determined to anneal them also. There are many circumstances however wherein it is obviously difficult to avoid working steel at a low or brittle heat; and therein lies one of its great dangers.

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Corrosion.—No enquiry into the relative suitability of such materials as wrought-iron and steel for permanent constructive works would be complete, which took no account of their respective capacities to resist corrosive influences. Both of them are obtained from the mixtures of metallic and non-metallic oxides which we call ores. These ores when found are, as regards further oxidation, in a stable condition; whereas the purer the derived metals, the more unstable they are. They are always seeking, as it were, to return to their primitive condition; and this return we call corrosion.

To prevent it, requires constant care, watchfulness, and expense. Coating with paint is the usual device. This is an attempt to cover with an air-tight film of metallic oxides or metalloids, themselves in a stable condition. In order to secure adhesion it is customary to mix these with vegetable oil, a substance which is not in a permanently stable condition. Pure metallic-oxide coverings, such as that which is obtained by the Bower-Barff process, might be expected to last for ever. But it is only too well known that the protection afforded by painting is of limited duration, and that corrosion goes on in spite of it. Indeed any iron or steel structure in the open air, well painted and then neglected for say ten years, will by that time be found to have shed off almost every vestige of paint; and nothing but a rapidly rusting surface will be visible. Therefore the intrinsic anti-corrosive qualities of the metals forming permanent structures, such as railway bridges and roofs, are of the greatest importance.

Authorities differ widely as to the relative liability to corrosion of wrought-iron and steel. Sir Lowthian Bell said at Paris in 1878* that he should have expected *a priori* that steel would corrode less than iron, because the first was pure and homogeneous, and the second composed of alternate layers of metal and cinder. Every statement of so high an authority as your ex-President deserves most serious consideration. But after much reflection upon this particular one, I have hitherto been unable to assimilate it. The cinder which is the principal impurity in wrought-iron, which causes

* Journal of Iron and Steel Institute, 1878, p. 450.

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its diminished tenacity and gives it its superiority in welding, is a basic silicate of iron. It is in a perfectly stable condition, or in other words a perfect paint. Lumps of it exposed for years to atmospheric influences will still be found unaffected by corrosion. Mild steel is nearly pure metallic iron, and there is nothing in it (except minute quantities of carbon &c.) which is not unstable, and eager to return to its primitive oxidised condition. The lines or layers of metallic iron in commercial wrought-iron are of course as liable to corrosion as mild steel. But every line and every layer is surrounded and coated with a film of non-corrodible cinder. It is in a sense painted throughout. No doubt these sheaths of cinder are not completely continuous, and therefore corrosion will work its way through in time. But their tendency must be to impede it. Wrought-iron therefore, containing as it does a smaller proportion of corrodible material, and intermixed as it is with a larger proportion of non-corrodible material, may I think be expected *a priori* to be less liable to a rapid return to its pristine condition than the purer article mild steel: and not more so.

But after all, this question must be decided rather by direct experiment than by *a priori* expectations. The British Admiralty appointed a committee in June 1874 to examine into the causes of corrosion in marine boilers. That committee investigated the subject very carefully, perseveringly, and conscientiously. Nothing done before or since can compare in extent or importance with the results of their labours. They took evidence of leading chemists, metallurgists, engineers, iron and steel makers, naval engineers, inspectors of steamer lines, Board of Trade and Lloyd's officers, foremen boiler-makers, and others; and they visited the principal localities and works in the country where there was a reasonable prospect of obtaining information. After three years of laborious work they published their final report in 1877. In it they say that the opinions given by the authorities they examined were so utterly divergent that they had been compelled to reserve their own until they had attempted to reconcile some of the discordant statements by actual experiments. Of these they had made a long and careful series.

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The specimens operated on included sixteen kinds of iron and steel plate discs, including ordinary and high-class iron, Lowmoor iron, Bessemer, open-hearth, and crucible steel, and Whitworth compressed steel. These were tested in fresh water from several sources, and sea water of various degrees of saltness; in land and marine boilers; in the water space, the steam space, and at water-level; with air admitted, and without; with lubricants in the water, and the reverse; with zinc, and without. The conditions which applied to one specimen applied to all in each case.

The following is the pith of the committee's conclusions in their own words:—

"It was reasonably expected that . . . those materials made by fusion, and consequently free from cinder, and in a condition of more perfect mixture, should have resisted the 'pitting' action much better than piled iron. Such however is not the case." *

"Not only does iron withstand corrosion much better than steel, but the commoner brands of iron withstand it better than those of higher qualities." †

In May 1881 Mr. W. Parker, chief engineer surveyor at Lloyd's, read a valuable paper before the Iron and Steel Institute on the "Relative Corrosion of Iron and Steel." In his view the deductions made by the Admiralty Committee were open to exception, because he thought sufficient care had not been taken to avoid galvanic action. He had therefore made experiments himself, taking extra precautions to obviate this danger. He also operated upon discs made of iron and steel plates, arranged in groups of eleven similar specimens each. Some of the experiments were specially made to ascertain the effect, protective or otherwise, of scale. In the remainder, which alone need here be considered, the discs were turned bright, in order that the intrinsic anti-corrosive properties of the metals might severally be tested.

Two of the specimens in each group were of common iron containing a maximum of cinder; five were of high-quality iron from South Yorkshire; and four were of the best brands of modern mild

* Third report of Admiralty Boiler Committee, p. xxxvii.

† Ibid, p. xvii.

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steel. The specimens composing each group were separated by glass ferrules to ensure insulation, and they were otherwise arranged to obviate all known or possible objections.

One group was exposed to the atmosphere [on the roof of a London building for 455 days. A second was fixed under sea-water level at Brighton 437 days. A third was subjected to the action of bilge water in a steamer 240 days. And three other groups were hung in the water spaces of different marine boilers for 361 days.

The results are given by Mr. Parker in a tabulated form.* If an average be taken of the behaviour of the three classes of materials under the six different conditions to which they were subjected, it will be found that South Yorkshire high-class iron corrodes 9·4 per cent. more than common iron, and mild steel 40 per cent. more. Thus the Boiler Committee's conclusions were decisively confirmed by the experiments of Mr. Parker, who certainly, from the tone of his paper, could scarcely be considered a willing witness.

Within the last two or three weeks additional evidence of an important and almost conclusive character has come under my notice. In the year 1871 Mr. James Rutherford, land agent and manager of the estate of the late A. H. T. Newcomen, Esq., of Kirkleatham, Yorkshire, had occasion to put up a certain quantity of wire fencing at a place five miles distant from the sea. For a portion of this, iron wire was used, and for another portion steel wire of equal substance. Four years later an exactly similar experiment was made at another part of the estate situated about half a mile from the sea. In both cases the fencing was coated with ordinary gas tar to begin with, and this has been renewed once since. The samples which Mr. Rutherford has sent me (and which I exhibit) tell their own tale. Those which are of iron are very much alike, and very little corroded in either case. They would certainly last out the present century. The steel samples on the contrary are badly corroded in both cases, and those nearest to the sea are almost eaten through, and unfit for further use.

But whether the advantage lie with iron or with steel as regards intrinsic anti-corrosive qualities, it must be admitted that neither

* Journal of Iron and Steel Institute, 1881, p. 46, Table II, column 9.

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metal can safely be left long without protection. Indeed maintenance of an innocuous protective film seems to be the grand desideratum, whether the internal surfaces of a boiler, or the external surfaces of other structures, be in question.

Boilers are in existence, both of iron and steel, which have been in operation from twenty to thirty years. My firm has some iron ones twenty years old, and a recent examination detected no diminution in the thickness of the shells. Mr. W. Richardson, of Oldham, reports similar experience with a number of steel boilers under his care. Some iron boilers taken out of steamers plying on Windermere had been in use thirty years.* But in all these cases the water was good; not in the sense of being chemically pure, for that does not seem to answer at all; but containing a small quantity of calcareous matter in solution, sufficient to form and maintain a thin, hard, protective coating. Indeed the same advantage has often been artificially secured by a coat of Portland cement inside boilers.

But if we are proud of boilers which can be made to last thirty years, we should scarcely be so of bridges or roofs which fell within a century or two of their erection.

It is curious to observe the insidious beginnings of corrosion. However well coated a structure may be to commence with, small rusty spots denuded of paint begin to appear in three or four years. Near them little blisters are seen. These can be rubbed off, and the surface below will be found to be rusty. Every blister seems to increase gradually itself, and to propagate fresh ones round it. In time they all unite and fall off, leaving a bare unsightly corroded surface. What is the explanation of this? Is it due to atmospheric moisture getting through the paint? The blistering observed, indicating pressure outwards, seems to negative this view. The corrosion apparently commences and goes on *under* the paint, until it pushes it off.

But for the iron to corrode under an air-tight casing, oxygen must be supplied from somewhere; and the blisters would seem to correspond with hydrogen being released concurrently. If moisture

* Third report of Admiralty Boiler Committee, p. xxxi.

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be not present, some other substance containing similar elements must be. What is that substance which furnishes materials for corrosion? I am disposed to think it is the *oil* in the paint. Oil consists of oxygen, hydrogen, and carbon. May it not be that the iron slowly decomposes the inner surface of the coating, uniting with the oxygen, setting free the hydrogen, and pushing off the carbon and metallic oxides in the paint?

If however the initial paint, upon iron or steel structures, be renewed after two or three years, and before commencing to fall off, and if the same operation be repeated at similar intervals, the protective coating may be maintained. The quantity of oxygen available for corrosion in a layer of oil paint is of course limited, and becomes exhausted after a time, leaving only the innocuous ingredients behind. Fresh layers added afterwards give tenacity and stability to the covering, and do not appear to affect the iron within. I recently scraped the paint off at several places from some iron railings, which had been covered every three years for a quarter of a century. Between the external surface of the iron and the internal surface of the protective covering I found everywhere a thick layer of rust, much more than could have been originally present. With this exception the protection appeared to have been complete.

If the views above stated are correct, it follows that the favourite practice of dipping hot in oil requires reconsideration as regards iron and steel; and the same conclusion must be arrived at as regards oil painting, when applied to the naked surface of the same materials. Thoroughly well boiled tar contains no oxygen, and can have no corrosive action. But where colours and decorative effects are required, tar is evidently inadmissible. In such cases the endeavour should be made to prime or coat in the first instance with some substance unable to affect either metallic iron or oil. If this be done, there seems to be no reason why subsequent coatings should not be composed of oil with pigments as heretofore usual. The question however is perhaps rather one for chemists than for engineers; but in any case it deserves complete investigation.

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Very much more remains to be said as to the relative advantages of iron and steel for different purposes. But your patience and my time must by this time be fully exhausted. The conclusion we may fairly come to is, I think, that the sudden and complete revolutions, so frequently prophesied by those who jump to conclusions from superficial appearances, occur no more in the arts than in nature. The laws of gradual change, and of the survival of the fittest, apply equally in both cases. Steel soon proved itself superior to iron for rails and tyres, and complete supersession followed. In other departments, such as guns and marine boilers, similar causes have produced similar results. But where circumstances differ materially, so do consequences. Wrought-iron still preponderates in the heavy forge, the blacksmith's shop, the bridge and roof-building yard, and the agricultural implement factory. Though steel castings are of exceeding value for special purposes, there is no probability whatever that they will ever supersede iron ones generally. And with regard to ships, it may be said that though a steel ship is better than an iron one if built to the same scantlings, it is doubtful if it is equal to it when built substantially thinner. But whatever our present views may be on these important questions, we may rest assured that in the long run the fittest material will prevail, according to the peculiarities and necessities of each particular case.

It now only remains for me to thank you for the patience and courtesy with which you have listened to this somewhat lengthy, and, I fear, very imperfect address.

The PRESIDENT said that since the completion of his address he had received additional information which had to some extent modified the views he had therein expressed. In the first place he had

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been informed by Mr. Parker, Lloyd's chief engineer surveyor, that their tests had recently been altered in an upward direction. For instance, instead of from 27 to 31 tons per square inch, the range for the tensile strength of steel had been raised to from 28 to 32 tons. In the second place he had sent a copy of the address beforehand to Mr. Parker and to Mr. Martell, Lloyd's chief surveyor, asking them to be kind enough to criticise it; and they had accordingly done so. Of course from their great and exceptional experience they were able to throw additional light on some points which had perplexed him, and generally to give additional information of considerable value. He had not yet had time to consider their comments; but as soon as the work of the present meeting was over it was his intention to do so, and to add in an appendix such remarks as might seem to be necessary. It would therefore be understood that the section relating to steel and iron shipbuilding must be taken as subject to such corrections as he might make in the appendix (see pages 347–8).

With regard to steel castings, it would be observed that he had said that all steel castings must be annealed. Since completing the address he had ascertained that at some steel foundries annealing was being dispensed with occasionally, that is in the case of castings for certain special purposes.

The specimens referred to in the address were on the table for the inspection of the meeting. They included pieces of iron and of steel fencing-wire which had been subject to similar atmospheric conditions in two localities, as explained in the address (p. 341); the steel in each case was much more deeply corroded than the iron. There were also samples showing the peculiar brittleness of steel when worked at a straw colour and blue temperature (p. 337).

The MAYOR OF LINCOLN said it was his pleasing duty to propose that the best thanks of the Institution be given to the President for his able interesting and instructive address. He felt sure that every one who had listened to it attentively could come to no other conclusion than that steel for many purposes was far superior to iron. He had been greatly struck with the suggestion that steel

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(The Mayor.)
should be used instead of wood for sleepers. It appeared to him however that that would be false economy unless there were an inexhaustible supply of a common ore which might be used for railway sleepers; otherwise a material which could not be reproduced would be used up for replacing one which could be. The one could be grown, but not the other. But this was a matter for other consideration than his own.

Mr. CLAYTON said he had great pleasure in seconding the resolution proposed by the Mayor. He was sure they all felt greatly obliged to the President for his admirable address. For himself he had been greatly instructed by it, and felt sorry when it came to a conclusion.

The vote of thanks was cordially passed to the President for his Address.

The PRESIDENT, in acknowledging the vote of thanks, said he had only to add that his sole object in investigating the matters dealt with in his address had been as far as possible to find out and circulate the truth. If in any matters he should be found to have been mistaken, he should be quite as anxious to make the necessary corrections as those who were good enough to point out errors.

APPENDIX TO THE PRESIDENT'S ADDRESS.

The criticisms upon my address, which Messrs. Martell and Parker, of Lloyd's Register, were so good as to hand to me, but not in time for consideration at the Lincoln meeting, are substantially the following:—

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1st. They admit that ship-plates, regarded as broad girders, and strained upon the flat, will sustain loads proportionate to the square of their thickness. But they contend that the plates forming the shell of a ship's hull are not so strained in actual work. They think that a ship should be regarded as a large box-girder; and that, whether in traversing the waves she is supported mainly at the ends or mainly in the middle, the resulting stresses in the upper and lower members of the girder (or portions of the shell corresponding thereto) are purely tensile, or purely compressive. They contend that, so regarded, the strength of the plating varies directly as its thickness, and not as the square thereof. And they consider that the internal framework of a ship is sufficient to maintain the form of the shell, and to keep the plating in line under the ordinary stresses encountered at sea.

My reply to the above criticism is, that I admit fully all contended for, except that it appears to me that the plates forming the shell of a ship may nevertheless be sometimes strained as flat girders. Thus when a ship is moving along a quay wall, or past another ship, with a fender (say a wooden roller) between, the plates will be apt to be bent inwards between each frame, with a facility varying inversely with the square of their thickness. Perhaps the case quoted in page 316 of the address may have arisen in this way. Also it seems to me that contact with icebergs, rocks, wreckage, or muddy bottoms, may at times produce local pressure upon portions of the plating of a ship, in such a way as to render the stiffness due to thickness an important factor in resisting local change of form.

2nd. Messrs. Martell and Parker state unhesitatingly that no steel ship built to the *present* steel scantlings of Lloyd's rules has been found to exhibit symptoms of structural weakness. They affirm exactly the same of iron ships, built to iron scantlings. They admit that cases of weakness have from time to time been reported; but when investigated these have invariably been found to have resulted from errors or deviations for which their officials were not responsible, or from careless stowage of heavy cargo, or from other negligence.

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These statements relate entirely to matters of fact which Lloyd's officials have observed and recorded. Outsiders can only congratulate the Committee that their accumulated experience enables them now to specify with certainty how to build a perfectly strong and satisfactory vessel either of steel or of iron.

3rd. Messrs. Martell and Parker say that, if the use of steel of a lower tensile strength than is prescribed by Lloyd's rules, combined with proportionately increased scantlings, is not permitted, it is simply because no such permission has ever been sought for. They concur in the opinion I have expressed in page 317, that a ship built of 24 or even 22-ton tested steel would be superior to an iron one of similar scantlings; and they are sure that any proposal to put this idea in practice will receive the most favourable consideration from their Committee.

I regard this declaration as of considerable importance, and am glad that my address has had the effect of eliciting it; not only because it is a matter of interest to mechanical engineers, but also because it may have an important bearing on the future of the iron, steel, and shipbuilding industries.

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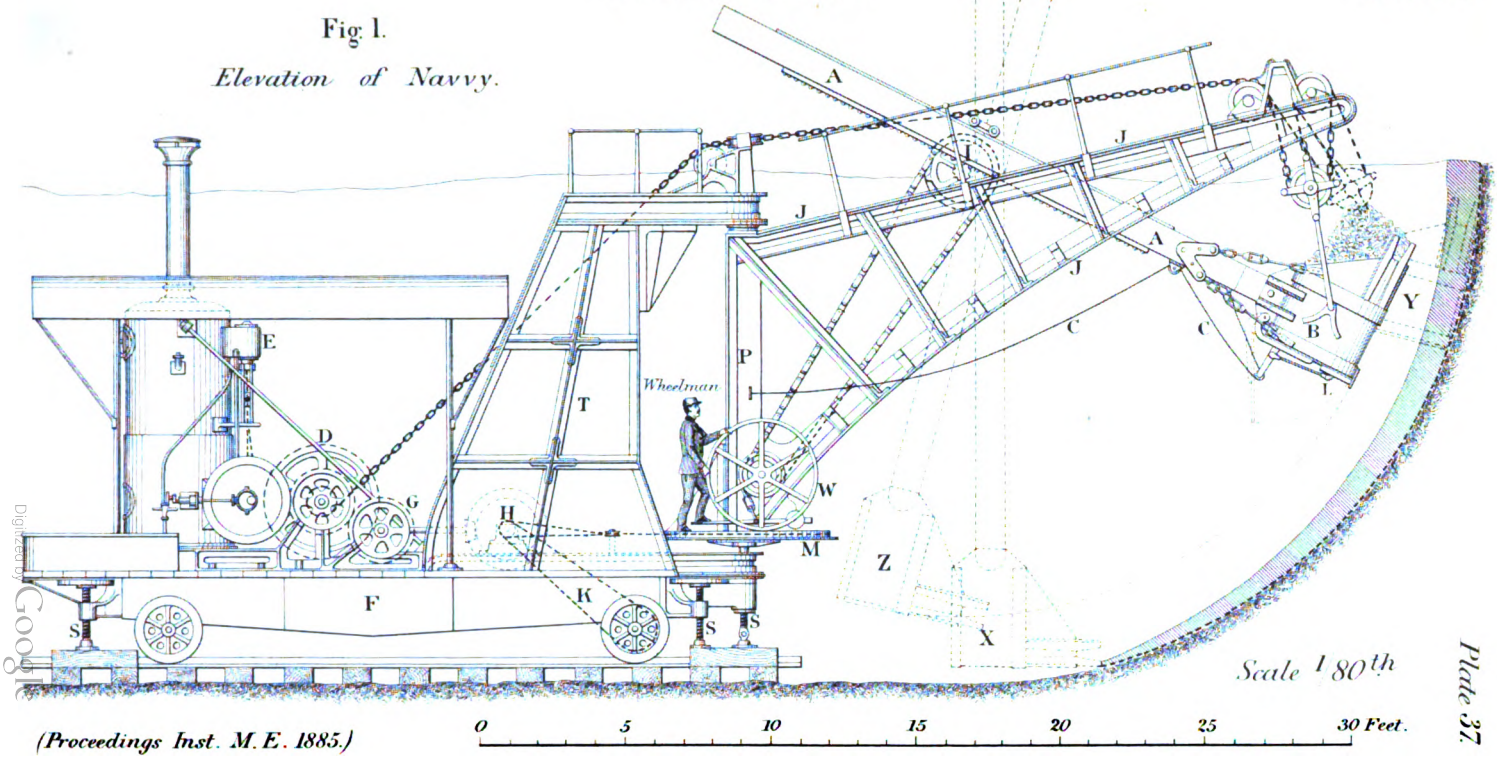
STEAM NAVVY.

Plate 37.

Fig. 1.

Elevation of Navvy.



(Proceedings Inst. M.E. 1885.)

Plate 37.

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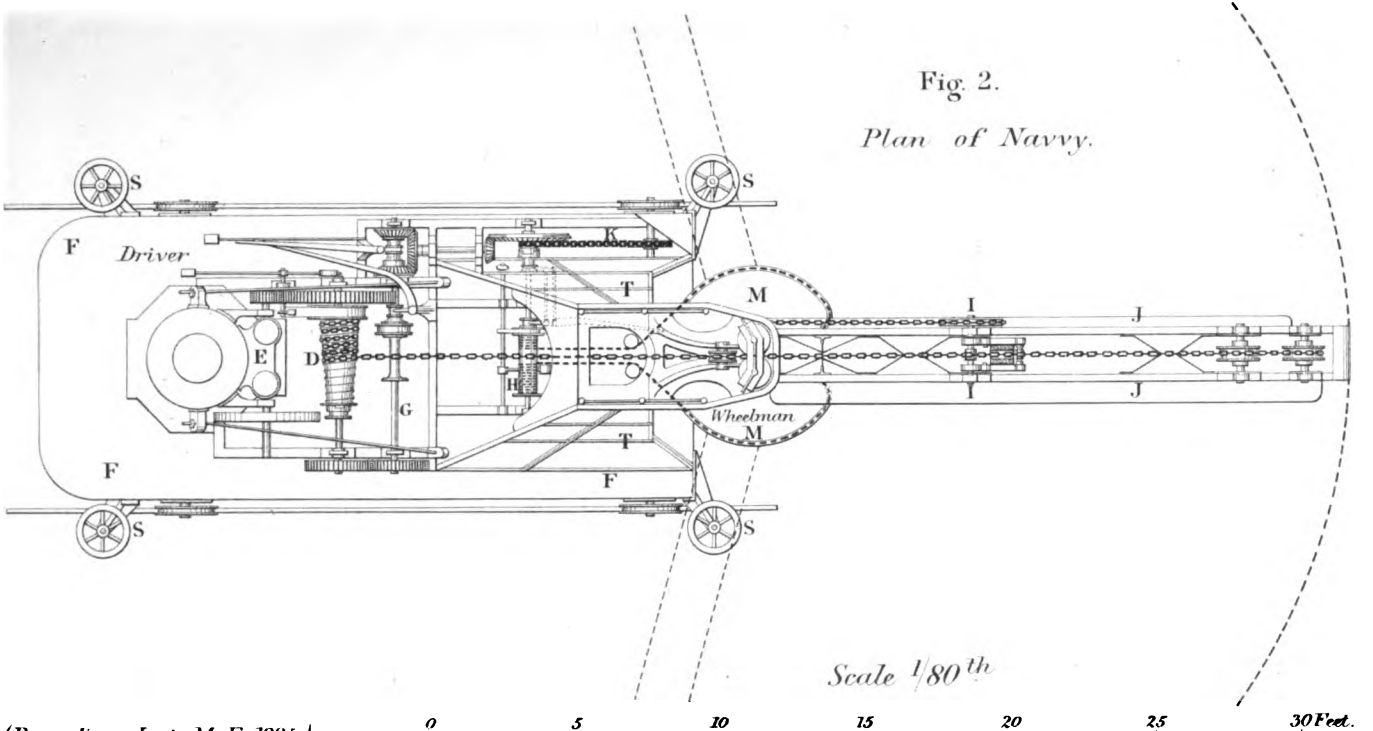

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Plate 38.

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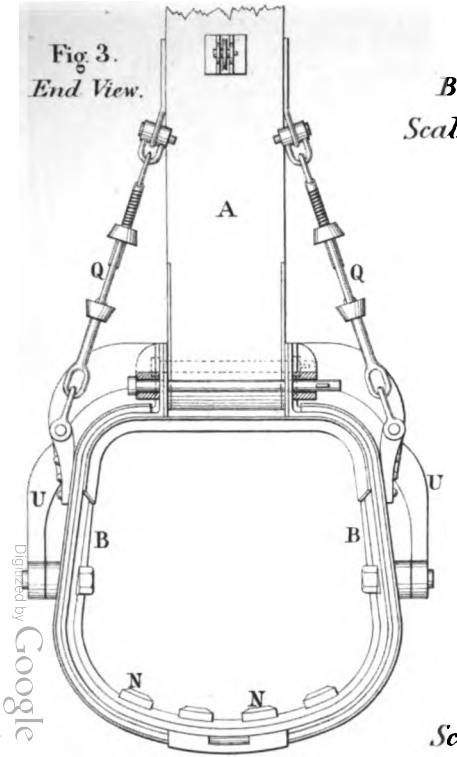
STEAM NAVVY.

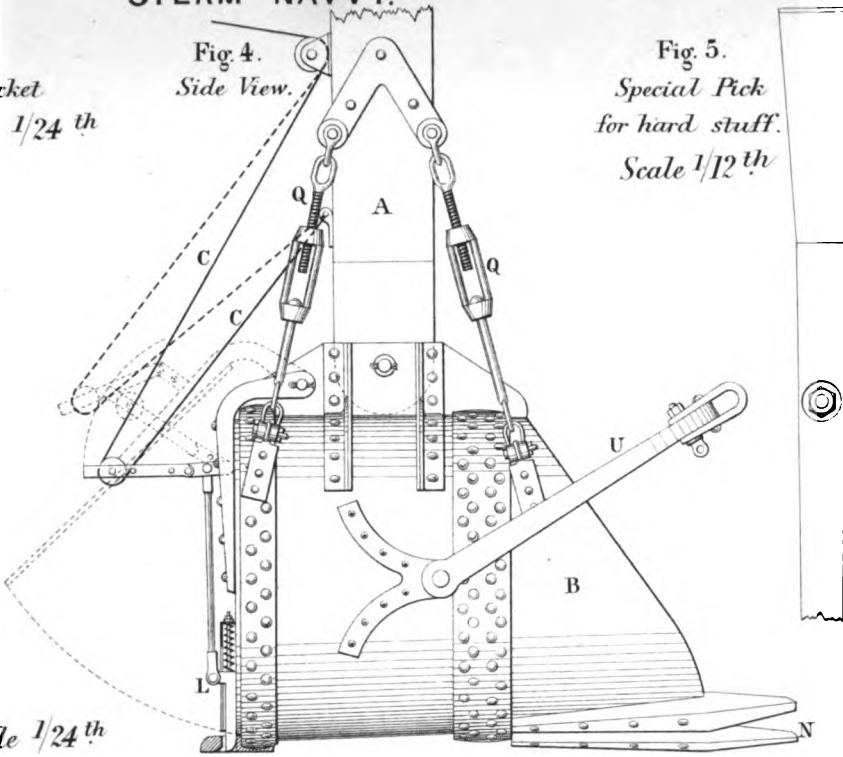
Plate 39.

Fig. 3.
End View.



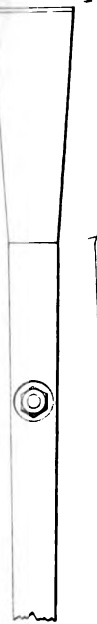
Bucket
Scale 1/24 th

Fig. 4.
Side View.



Scale 1/24 th

Fig. 5.
Special Pick for hard stuff.
Scale 1/12 th



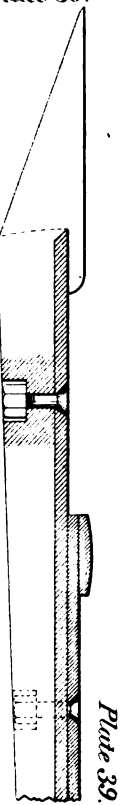


Plate 39.

(Proceedings Inst. M. E. 1885.)

Ins. 12 6 0 1 2 3 4 5 6 Feet.

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Fig. 6. Plan.

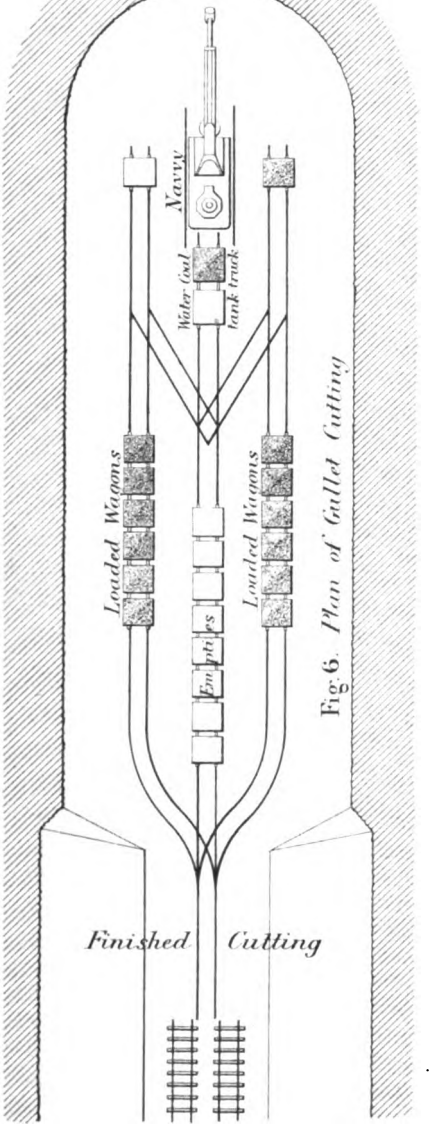

Fig. 6. Plan of Gullet Cutting

Fig. 8. Plan.

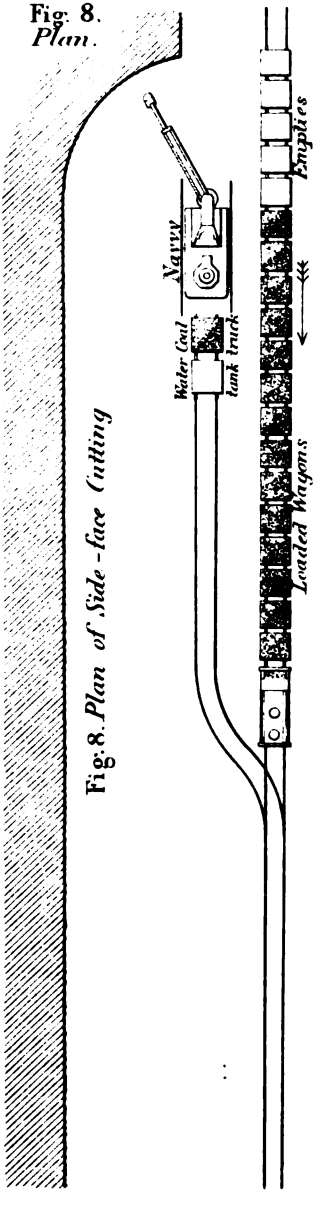

Fig. 8. Plan of Side-face Cutting

Gullet Cutting.
Fig. 7. Section.

Side-face Cutting.
Fig. 9. Section.

(Proceedings Inst. M.E. 1885.)

Scale 1/600th

10 0 50 100 150 Feet.

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STEAM NAVVY.

Fig 10. *Double-line Railway Cutting, 25 feet deep. Taken out by one gullet, with double road to Navvy.*

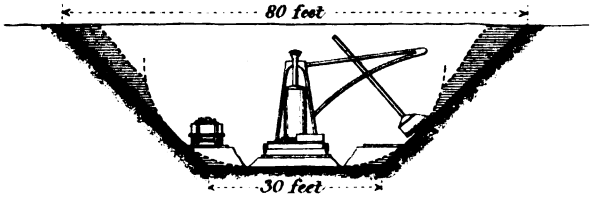


Fig 11. *Double-line Railway Cutting, 50 feet deep. Taken out by three gullets, with double road to Navvy.*

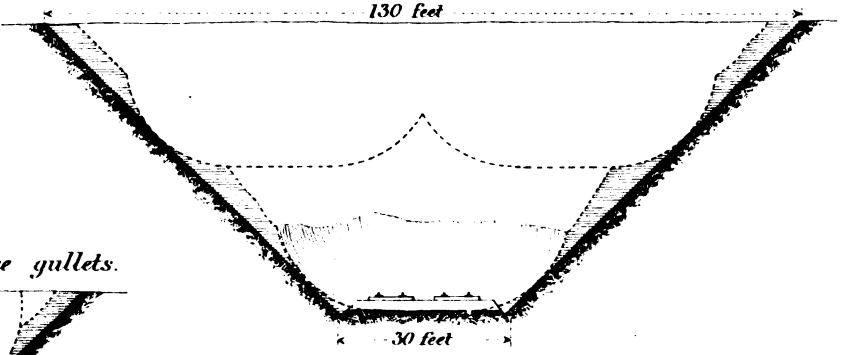


Fig 13. *Canal, 20 feet deep, taken out by three gullets.*

Fig 12. *Single-line Railway Cutting, 25 feet deep. Single road to Navvy.*

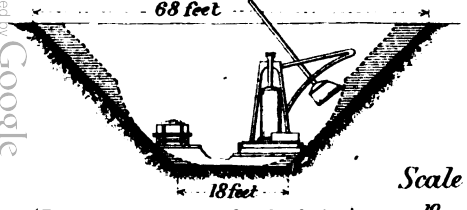
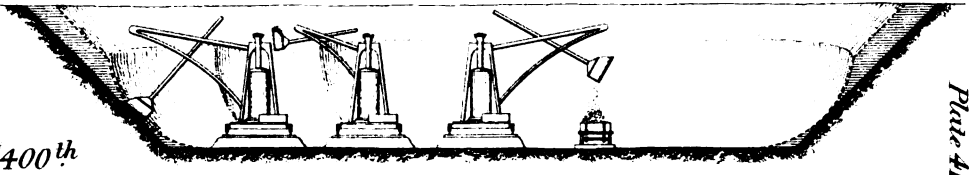


Fig 14. *Dock Cutting, 25 feet deep. Double road in gullet, single roads to side cuts.*



Scale 1/400th

10 0 50 100 150 Feet.

(Proceedings Inst. M. E. 1885.)

Plate 41.

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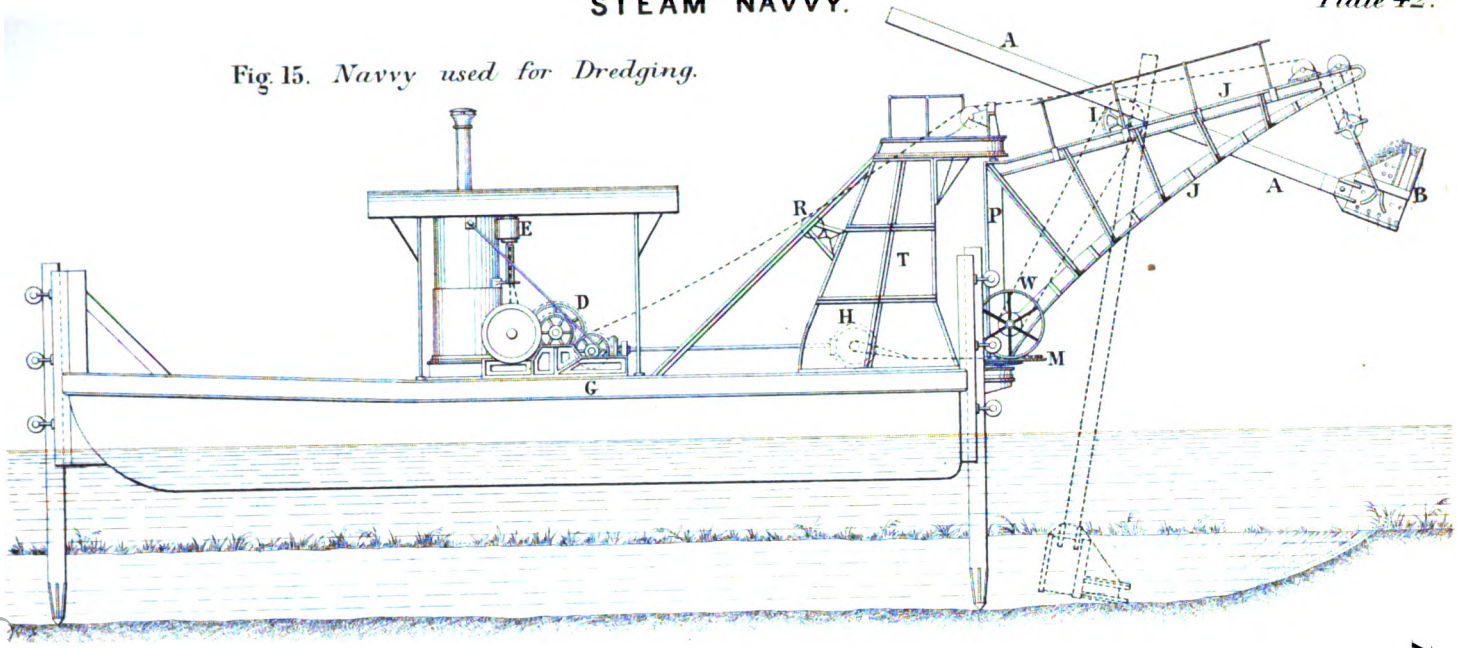
STEAM NAVVY.

Fig. 15. *Navvy used for Dredging.*



(Proceedings Inst. M.E. 1885.)

Scale 1/130 th

0 10 20 30 40 50 60 70 Feet.

Plate 42.

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DESCRIPTION OF DUNBAR AND RUSTON'S STEAM NAVVY.

By Mr. JOSEPH RUSTON, M.P., of Lincoln.

In the large excavations constantly being made for railways, docks, canals, and other engineering works, containing often many hundreds of thousands of cubic yards, a substitute for the pick and spade has long been sought, and various mechanical contrivances have from time to time been adopted with more or less success. The problem may however be considered to be now solved by the Steam Navvy forming the subject of the present paper, which is believed by the writer to be perhaps the most successful machine yet introduced for this end, being not merely suitable for one form of digging or for one kind of material, but also capable generally of dealing with every large excavation which contractors are called upon to make, and thus proving itself in fact an expeditious, reliable, and most advantageous help. So successfully has it fulfilled the purpose in view, that its use on all works of any magnitude, at least in this country, is the rule rather than the exception; and its manufacture forms an important branch of the business at the writer's works, from which upwards of a hundred of these machines have now been turned out, the majority for use in Great Britain, and the remainder distributed in various parts of the world. Among the completed works on which it has been employed with special success may be mentioned the following:—Victoria dock, London; Coble Dene dock, Tynemouth; Penarth, Swansea, Silloth, and Greenock docks; new outfall works for the river Witham at Boston; harbour works at Calais, and at Melbourne, Australia; cuttings on the Great Northern and the London & North Western Railways at Melton Mowbray, the Midland Railway at Manton and Bootle, the Dover and Deal Railway at Dover, the Rugby and Northampton, the Paisley, and the Didcot and Southampton Railways, the Lanarkshire

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lines at Airdrie, the North Eastern Railway at Bishop Auckland, the Guildford & Surbiton and the Rhymney Railways; and other works.

The steam navvy excavates and delivers into wagons any material capable of being cut, such as sand, gravel, chalk, and clays of all kinds, digging out with equal facility the hardest and toughest, such as require blasting when worked by hand. It can also deal with these materials when thickly interspersed with stones and heavy boulders; and without being unduly strained it cuts through seams of flints, shale, slate, or even sandstone, which may intersect the face of the excavation it is at work upon. With the assistance of blasting, it is also used with advantage in much more difficult stuff, such as hard marl and lias rock.

Development.—Since its introduction many improvements have been made, increasing its power and efficiency. The framework has been considerably strengthened throughout, augmenting the total weight by several successive increments from 22 tons in the earliest machine to 32 tons, which is now adopted as the standard; the scoop averages a capacity about 25 per cent. larger than at first, and has an increased angular range. The duty has progressed in a greater ratio, nearly 50 per cent. having been added to the original output. At first 180 to 190 wagon loads were considered a good day's work; now 240 to 250 are often obtained, and even more under very favourable conditions: the day consisting of ten hours, and the wagons being the size ordinarily used by contractors, holding 3 cubic yards each, in which however the stuff is more solidly packed by the navvy than when they are loaded by hand. With extra large wagons holding 4 cubic yards each, an equal number has been filled in a day, equivalent to the grand total of nearly 1,000 cubic yards per day.

Construction.—The machine is shown in Figs. 1 and 2, Plates 37 and 38; Fig. 1 being an elevation, and Fig. 2 a plan. It may be described generally as consisting of a strong rectangular wrought-iron frame F mounted on wheels, forming a substantial base to which all the parts are secured. On the back end is placed the

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engine E, beside which the driver stands, Fig. 2. At the front end rises a wrought-iron tower T carrying the top pivot of a crane jib J, the lower pivot resting on girders fixed to the main frame. The jib may be said to be of twin construction, being composed of two sides which are united only at the post P and at the outer end or point; between them therefore is a long slot, in which swings an arm A of adjustable length, depending from a fulcrum fixed on the upper member of the jib; and at the base of the post is a circular platform, on which a man stands to regulate by means of a hand-wheel W the "reach" or length of radius of the arm A. The scoop or bucket B is fixed at the lower end of the arm A, and is raised or lowered by the main chain passing over the extremity of the jib.

Handling.—The whole of the movements are controlled by two men, called the "driver" and the "wheelman." The driver raises the scoop while making its cut, swings it round into position for discharging, and back again afterwards, and lowers it down. The wheelman regulates the depth of the cut, releases the scoop from the face of the bank, and opens the door or bottom for discharging its contents.

Supposing the navvy to be in position, the mode of working is as follows. The bucket having been lowered till its arm is vertical, as shown by the dotted lines at X in the elevation, Fig. 1, Plate 37, the wheelman regulates the length of the arm A by means of his hand-wheel, so that the cutting edge of the bucket shall get its proper grip of the soil. The driver throws the main-chain drum D into gear, and the scoop is dragged forwards and upwards by the chain into the position Y, describing a circular arc of about 80 degrees and cutting out the tapering slice indicated by the lighter shade. By the time it reaches the top it is fully loaded, and the driver throwing the drum out of gear holds it with a footbrake; at the same instant the wheelman by easing his footbrake allows the bucket to fall back to B, clearing itself from the face of the bank. The driver next swings the jib round till the bucket is over the wagon, when the wheelman releases the latch L by means of a cord C, and the door of the bucket falling open, the contents instantly drop through. The driver then

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swings the jib back again, and at the same time lets go the footbrake of the chain drum, thus causing the bucket to descend through a sort of spiral course, until he brings it up sharply by the brake again when in position Z. The wheelman at the same moment adjusts the fall by means of his brake, so as to lower the bucket to X again, with just the right reach of arm for the next cut. During the fall the door of the bucket closes and latches itself automatically by its own weight; and all is then ready for repeating the operation.

Although apparently somewhat complicated when thus performed in combination, the several movements are each very simple; and the whole cycle can be performed in less time than has been taken to describe it. Three quarters of a minute is sufficient for scooping out from 1 to 2½ tons of stuff, according to the capacity of the bucket, for dropping the stuff into the wagon, and for returning the scoop into place ready for another cut.

After the machine has dug out all within reach, the jack-screws S which steady it are eased; and the propelling gear being put in action, it is moved forwards 3 or 4 feet; the screws are then tightened down, and another series of cuts is commenced. The cuts all radiate from the centre round which the jib swings; and they may together form a hole more or less resembling a crater, according to the plan adopted in making the excavation, as shown in Plate 40, which will be described subsequently.

Details of Construction.—Proceeding to the constructive details of the navvy, the main frame F, Plate 37, has its side girders formed deeper in the centre than at the ends; and they are duplicated on each side at the front end under the tower T. There are three internal transverse girders, and longitudinals again under the engine and gearing; all are well tied together, and stiffened by angle-irons and gussets. Between the inner longitudinals under the tower a large tank is formed, which when filled with water acts as ballast to steady the machine, and forms a convenient supply for the engine. The whole frame is riveted together at the works; but to facilitate transport it is divided crossways in the centre, and the two halves are united by bolts and joint plates.

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The lower pivot of the crane post P is carried somewhat in advance of the main frame F by a pair of projecting girders riveted on the top of the transverse members of the frame, and converging in the form of a V to an apex, at which is placed the pivot; these are further stiffened by plates underneath, and the front end of the frame where they are fixed is made of double thickness the whole way across. This construction has been found necessary in order to provide for the enormous stress which has to be resisted at this point if the bucket is allowed to jam itself when cutting; the force is indeed sufficient sometimes to lift the back or engine end of the machine almost off its legs. The plan of carrying the pivot well in advance of the main frame, which is a distinctive feature of the navvy, enables the jib to be swung round further, and renders the ground in front much more accessible when laying down the rails.

At each corner of the frame is a strong jack-screw S, and a fifth is placed immediately under the pivot of the crane post; these take the entire weight when at work. The outside wheels on which the machine is mounted are double-flanged and 10½ feet gauge; and for transport from one cutting to another ordinary single-flanged wheels are also furnished inside, to the standard 4 ft. 8½ ins. gauge.

The tower T may be described as an oblique truncated pyramid, well extended at the base for bolting to the longitudinals of the main frame. It is formed of two plate-sides, stiffened with T irons, and braced together with crossplates and stays; between them is an opening large enough for the driver to watch the motion of the bucket, even when the jib is straight ahead. The top of the pyramid is finished with a roof-plate extended forwards in front for taking the top pivot of the jib, and stiffened by a V shaped girder like that for the bottom pivot; on this table are placed also the guide pulleys for the main chain, Plate 38.

The jib J is stiffened laterally by riveting to its lower member on each side a broad plate placed on edge so as to form an L section, the two sides of the angle being united with knees and gussets. This enables it securely to withstand the heavy twisting strains when cutting in any such material as tough clay mixed with

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boulders. Round the platform M at the base of the post are led the chains connected with the swinging gear.

The engine E is of the ordinary vertical type, with a cross-tube boiler carrying usually 80 lbs. pressure, and a pair of cylinders of 10 HP. nominal; it runs up to 160 or 170 revolutions per minute under the control of a governor. On the crank-shaft is keyed a pinion, gearing into a spur wheel four times its size on the main-drum shaft, from which all the other motions are transmitted.

The main drum D, Plate 38, is tapered, so as to give the engine the most power when the chain is pulling at least advantage, and *vice versâ*; it is loose on the shaft, and is driven by a clutch, and controlled by a powerful footbrake. By a pair of equal spur-wheels motion is given to a second shaft G, on which is mounted a small drum having its own clutch and brake, and winding a light chain for pulling the bucket back; this however is very seldom required, except when the machine is used for dredging.

On the other end of the second shaft G is a double-cone friction-clutch with a pair of reverse bevel-wheels, for driving in either direction a short longitudinal shaft, which at its front end drives a third cross-shaft giving motion to the swinging and propelling gears through a double-ended clutch. A drum H on the shaft winds the swinging chain that is led round the circular platform M on the foot of the crane post; and this drum also has a brake under command of the driver. A pitch-chain K from a pinion upon the shaft drives a wheel keyed on the axle of the front travelling wheels. By means therefore of the bevel wheels and friction cones the driver can move the navvy backwards or forwards, or swing the jib in either direction; and all the different movements can be effected without reversing or stopping the engine, so that no time is lost. A strong cast-iron framework, firmly bolted to the main frame, carries the various shafts.

The bucket arm A, Plate 37, is made of two oak planks, bolted together at top and bottom so as to leave a long slot between them, through which passes the main chain. On the back edge of each plank is a rack, gearing with a pinion fixed on the fulcrum shaft I

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on the top of the jib. The same shaft also carries a swing frame provided with four rollers, which press on iron bars or runners fixed along the front edge of the arm, so as to hold it up close to the fulcrum, while yet allowing it to be moved longitudinally by the racks and pinions for lengthening or shortening it; the movement is given by a pitch-chain wheel on the outer end of the fulcrum shaft I, driven from a pinion on the hand-wheel shaft W, which as already explained is under the control of the wheelman.

The main lifting chain passes from the winding drum D, through the tower T and over the pulleys on the top, through the bucket arm A, over a sheave on the end of the jib J, round a snatch block on the handle of the bucket B, up to another sheave on the jib, and down again to the snatch block, obtaining therefore a treble purchase.

The bucket is shown in detail to a larger scale in Figs. 3 and 4, Plate 39. Its mouth is semi-elliptical, Fig. 3; its cutting edge is of steel, and is protected by four strong picks or teeth N, Fig. 4, which are made so as to be easily renewed when worn, being fixed to the lip of the bucket by countersunk bolts and nuts, as shown in Fig. 5. These picks or teeth are of different strengths according to the stuff to be excavated; in Fig. 4 is shown the arrangement for ordinary material; the chisel-shaped head of one of the stronger kind is shown to a larger scale in Fig. 5, and is suitable for the hardest boulder clay. On the top of the bucket are fixed two plates strongly gusseted, between which the lower end of the arm A is secured by a through pin. There are also four shackles Q furnished with screw swivels, which distribute the strain, and permit the adjustment of the angle that the cutting edge of the bucket makes with the arm. The two top plates also carry the L shaped hinges riveted to the flap or door. The handle or "bale" U of the bucket swings on pins fixed about centrally on each side; it is well arched to allow room for the dirt, and is secured to the snatch block by a pin and strap. The door is fastened by a stout bolt L, fixed on the outside opposite to the hinges, and kept closed by a spiral spring protected by a casing. On the bolt is a short arm passing through a slot in the casing, and connected by a link to the catch lever for opening the door; at the outer end of this lever is a pulley, round

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which a cord C is rove, the free end passing through a sheave on the bucket arm A and thence to the wheelman. By pulling the cord the bolt is withdrawn out of its socket, and the door falls open by its own weight, and hangs vertically; when the bucket falls back from position B to Z, Fig. 1, it overtakes the door, and the bolt and socket being both made with sloping edges, the door latches itself automatically in closing.

Plan of Excavation.—When making a cutting, the navvy first drives a "gullet," unless the excavation be commenced along the side of a bank or hill, as shown in Plates 40 and 41. The output depends mainly upon the completeness of the means for removing the excavated stuff.

The most effective way is to provide double roads, one on either side, branching out by proper curves from a central road, and also connected with the latter by short "jump" lines at abrupt angles immediately behind the navvy, as shown in Fig. 6, Plate 40. On the central road are kept the empty wagons, and on each side is a man with a horse, by whom an empty wagon is brought forwards along the jump to the side of the machine; and as soon as it is filled it is run back along the branch, and another empty is brought up. Meanwhile the wagon on the other side is being filled; and whilst this in its turn is being exchanged for an empty, a second wagon is being filled on the first side. As the work thus proceeds on either side alternately, not a moment need be lost in waiting for wagons; and the jib has the minimum distance to swing round, the dirt from each half of its sweep being delivered on its own side. When say a dozen wagons have accumulated on each of the side roads, the shunting engine makes up a train, and takes them away to be tipped. The central siding behind the machine should be long enough for say thirty wagons at least; and other sidings are of course necessary if the "lead" to the tips be a long distance.

The gullet thus made, Fig. 7, may be 20 or even 30 feet deep, according to the nature of the stuff; but 25 feet is about the most economical depth, because the machine has then sufficient reach to make the cutting exactly large enough for an ordinary double-line

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railway of standard gauge, the slopes requiring very little hand-work to finish them, as shown by the section in Fig. 10, Plate 41. In Fig. 11 is shown a cutting 50 feet deep for a similar railway, which can be best made by driving two navvies, one in advance of the other, to take out the first 25 feet; and then finishing the lower half of the depth with a gullet similar to that shown in Fig. 10. In each case the completed cutting is shown by the dark section, and the part to be taken out by hand by a lighter shade. In the deep cutting, Fig. 11, the sleepers and ballast of the permanent way are drawn in; whilst in the other, Fig. 10, are shown the positions of the side roads while the work is in progress.

Where the railway has only a single line, as in Fig. 12, Plate 41, the cutting must be made narrower; the navvy is then placed out of centre, and one side-road only can be used. More attention is therefore required for keeping up the supply of empty wagons; and the jib having to swing round through a greater average distance, the output is not quite so good. In Fig. 12 is represented a cutting 25 feet deep for a single line.

For a wide canal, Fig. 13, Plate 41, three or more machines slightly in advance of one another may be used, the centre one leading. A similar arrangement was employed in making the new channel of the river Witham, near Boston.

After a gullet has been driven, the excavation may however be widened in another way, often employed in dock and harbour works, namely by working along a "side face" with a single road, as in Figs. 8 and 9, Plate 40. A train of empty wagons can then be drawn up alongside the navvy; and each truck as it is filled is pulled backwards by the locomotive, so as to bring the next one into the right place for receiving the contents of the bucket, no horse being then required. But although this appears a very simple plan, it is found difficult in practice to move each wagon through just the right distance; and time is lost, and the dirt spilt about. It is therefore best to store the empties behind the machine as before, and bring each forward over a jump to be loaded; in this way, with experienced men on the machine, two horses can be kept going. The jump lines should of course be as near to the machine

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as possible, and the central road should follow up close with the coal truck and the water-tank wagon. Two or more navvies also can be worked along the same face ahead of each other, the centre road forming the side road for the one behind, and so on; as in the section Fig. 14, Plate 41.

The size of the excavation, the material, the facilities for tipping &c., will in each case determine which system can be used with the greatest advantage. With the hardest and most tenacious clay, about 22 feet is the best depth, as then no wedging down is required of the stuff above the reach of the bucket teeth. With loose earth 30 feet can be just as easily taken, since it all falls down to the machine. Within these limits, the deeper the face the better, as the greatest quantity can then be scooped out between each forward movement. To stop, ease the jack-screws, lay rails, run the navvy forwards, tighten down the screws, and get to work again, requires from five to ten minutes, during which of course no wagons are filled. The fewer the stops in the day, the greater will be the number of wagons filled; and the larger the quantity of material within reach of the bucket, the less seldom need the navvy be moved forwards. A good deep gullet offers as a rule the most advantage, because the whole of the semicircle in front of the machine can be cut round, and not merely part as in the side-face cutting; there is better facility for changing the wagons smartly, and there is a shorter average distance for the jib to swing through in order to get over the wagon. All these things economise time and increase the duty, for a few minutes' loss now and then means fewer cubic yards got out in the day.

Men employed.—How small this loss is permitted to be depends even more upon good management than upon the system employed; and of equal importance is the skill of the driver and wheelman on the machine. From the nature of their duties it will be apparent that they must work well together; and good sense and smartness are necessary for obtaining the best results. When handy and suitable men are chosen, their training is soon accomplished; indeed by the time the excavating is in full working order, it will generally

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be found that the necessary dexterity has been acquired. The driver takes the lead, and is usually paid so much extra for each wagon filled per day beyond a stipulated number. If he fills 230 wagons, for instance, he receives his day's pay; but if 280 wagons, 1¼ day's pay; it is thus to his interest to take care no time is lost. Besides these two, there is a fireman to stoke and clean.

The rest of the help depends upon the cutting. As a rule there may be added one ganger and eight men, to act as plate-layers and lay the roads for the wagons and navvy, and to trim the slopes; one man on the top to break down the loose earth, and either one or two horses with their drivers: or say a total of fifteen men and two horses. Where the excavation is extra deep and of very hard material, another man may be required on the bank above, and perhaps extra help on the slopes. With these exceptions the labour remains fairly the same, whatever be the kind of stuff. For dock work, where the slopes do not require finishing till the side is reached, the labour will be proportionately somewhat less than in a railway cutting, and nine to twelve men may be taken as the average. When blasting is necessary, extra help has of course to be reckoned for.

Output.—The output is affected by the hardness of the stuff. For the very hardest clay intermixed with stones and boulders, the capacity of the bucket is 1 cubic yard; for all other hard stuff 1¼ yard, which is the most useful size; whilst for loose earth, sand, gravel, or drift, 1½ or even 1¾ yard can be used.

For all sizes of bucket the number of cuts per hour remains approximately the same, about three-quarters of a minute being the time necessary for each. Moving forwards, laying rails, and waiting for wagons, may be set down as a deduction of 10 minutes per hour, leaving 50 minutes for cutting, which gives say 60 as the number of bucket loads per hour, or 600 per day of ten hours, as the theoretical capacity, equivalent to a daily output of 600, 750, and 900 cubic yards with the 1-yard, 1¼-yard, and 1½-yard buckets respectively; and this agrees well with the results actually obtained.

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Working Expenses.—The working expenses vary according to the locality. The following examples, taken from two different contracts, in the south of England and in Scotland respectively, may be considered as representing the two extremes, the output being in each case about equal.

South of England.				*Scotland.*			
One engine-driver . . .		7	6	One engine-driver . . .		5	0
One wheelman		4	6	One wheelman		4	0
One fireman		3	6	One fireman		2	6
One ganger		8	4	One ganger		4	6
Eight men at 4*s.* 6*d.* . .	1	16	0	Eight men at 3*s.*	1	4	0
Two horses and two drivers	1	0	0	One horse and driver . .		10	0
One man at top		4	6	One man at top		3	0
10 cwts. of coal at 36*s.* . .		18	0	10 cwts. of coal at 6*s.* . .		3	0
Water, oil, and waste . .		2	6	500 gals. of water . . .			3
				Oil, tallow, and waste . .		2	6
Total per day . .	£5	4	10	Total per day . .	£2	18	9

In the first example the prices are all high, particularly that of the coal. In the second the prices are moderately low. The average may therefore be set down at from £3 10*s.* to £4 per day.

For depreciation, repairs, and interest on capital, about £1 per day may be reckoned, being arrived at as follows. The total cost of the machine weighing 32 tons is about £1250: namely £1175 price at the works, and £75 for carriage and erection on the site of the excavation; but in many cases the amount allowed for erection can be considerably reduced.

Depreciation at 10 per cent. on £1250 . . .	125	0	0
Repairs and renewals at 5 per cent. . . .	62	10	0
Interest on outlay at 5 per cent.	62	10	0
Total per year . .	£250	0	0

This amount may be considered to be well over the mark. Allowing therefore 300 working days in the year, and deducting two days per month for stoppages through bad weather, about 270 available days will remain. The amount to be reckoned under

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the above items will therefore be 18*s.* 6*d.* per day, or about one-third of a penny per cubic yard, or say from three farthings to one penny per wagon.

Making all allowances therefore, the total cost of the machine may be set down at say £4 15*s.* per day; which, divided by the output, gives as the cost of excavation say three halfpence per cubic yard for sand or gravel, and twopence for hard clay. Where the excavation is small, or the machine is under a disadvantage, these prices will of course be somewhat exceeded; and twopence to threepence per cubic yard may then be allowed. The following results, obtained directly from contractors using the navvy, show a substantial agreement in this respect.

Kind of cutting.	*Material.*	*Size of bucket. Cubic yard.*	*Cubic yards per day.*	*Cost per cubic yard. Pence.*
1. Dock works.	Boulder clay.	1	480	1½
2. Railway cuttings.	Chalk with stratum of flints.	1½	500	2½
3. Harbour works.	Clay.	1	660	3
4. Dock works.	Hard red marl.	1½	940	2
5. Dock works.	Hard red marl.	1½	740	2½

It is difficult to estimate the cost of doing the same amount of work by hand, but a saving of 2*d.* to 6*d.* per cubic yard may be safely reckoned upon. Where the stuff is hard it is still greater. For stiff brown clay 10¾*d.* per yard has been given as the cost; and for stiff hard tough clay, containing boulders weighing from ½ cwt. to 4 tons, the cost was estimated at 1*s.* 6*d.* per cubic yard by hand labour, whilst the cost was 4¾*d.* by the machine, which was one of the earliest sent out. With the present stronger machines the cost would have been still less; in short the harder the stuff, the greater is the economy over hand work.

Equivalent Hand Labour.—The number of men required to do the work by hand will vary very much. For instance, in excavating 190 cubic yards per day the following men were necessary:—one ganger, ten gullet men, seventeen wingmen, two platelayers, one brakesman, two horses and two drivers; or a total of thirty-three men and two horses. At the same rate to excavate by hand 600

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yards per day, as the navvy does, one hundred men would be required. The steam navvy may therefore be considered equal to at least seventy or eighty men.

The machine gives also the important advantages of enabling faster progress to be made, and economising time, as none is lost in disputes with the men; the cost of excavation can therefore be estimated with greater accuracy, and when once it has been determined for a given cutting, the rate may be relied upon till its completion. The contractor therefore is practically independent of strikes in this department of his business; and is further relieved of the trouble of getting together so large a body of men, and of housing and providing for them in out-of-the-way districts.

Subaqueous Work.—The navvy can also be worked for excavations under water, for which purpose it is mounted on a pontoon, as shown in Fig. 15, Plate 42. The pontoon is about 50 ft. long by 22 ft. wide, and draws 2½ ft. of water; it is built specially to receive the machine, and is most conveniently made of iron; but where timber is on the spot and plentiful, it may be of course substituted with advantage. For better distributing the weight in the pontoon, the frame of the navvy is divided transversely, and a distance piece is bolted in between for completing the continuity. Extra stays are carried back from the top of the tower down to the engine end; and an extra roller R is put in, to take the sag out of the main chain. Rollers are also provided under the step of the jib for the drawing-back chain that winds upon the drum on the second shaft. The bucket arm has of course to be lengthened, according to the depth to be taken out; and the bucket is made with rather more taper, for the stuff to clear itself, and is pierced with holes to let out the water. The action is similar to that on land, except that the resistance of the water somewhat impedes the back swing of the bucket, necessitating the use of the drawback chain. The pontoon is steadied by three piles or legs, one at each front corner on either side of the jib, and one centrally behind the engine; these are provided with racks and pauls, and are raised by hand levers; two or three crabs, with guy ropes attached to anchors or otherwise, are

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also necessary. The machine delivers into a barge moored on one side of the pontoon, a second empty barge being brought up on the other side ready to receive the stuff as soon as the first is full. When all within reach of the bucket has been excavated to the required depth, the piles are raised, and the pontoon hauled forwards by the guy ropes; the piles are then dropped again, and the next piece in front is excavated.

The deeper the face, the better; indeed a very shallow face can hardly be dealt with successfully. The water also should be comparatively still, as waves lift the pontoon and interfere with the bucket taking its proper cut; the output can be averaged at about half what it would be on land. The cost per cubic yard may be taken at about double that of a dry excavation with similar depth of face, up to say 6 feet; but it will also vary according to the depth below the water line.

As a dredger the machine has not been extensively tried. For mud and sand it is hardly considered as a competitor of the dredgers in ordinary use; but where there is a very hard bottom and a fair face to work at, it offers without doubt very considerable advantages.

Discussion.

Mr. RUSTON mentioned that on the occasion of the visit of the members to his works that afternoon one of the machines would be exhibited in full operation, except that it would not be actually excavating, but every movement would be performed in exactly the same way as in the actual work of excavation. The machine itself was one which so far had been a practical success, and indeed had exceeded any expectations which he had at first formed of it. However happy any idea might be, it was one thing to conceive it and another thing to bring it into successful operation. That was more particularly the case where machinery was subjected to the

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(Mr. Ruston.)
rough usage which it often met with in railway contracts and works of that kind, than it was in a well kept engine-house or factory such as many of those which mechanical engineers were accustomed themselves to control. The idea of the steam navvy however had been followed out from its origin, until the machine had become a perfect success. The parts which had at first been found to be weak had been strengthened, and the parts which required special adaptation had been carefully considered; and he believed that every one who saw it at work would be under the impression that it was very little else than a mechanical toy, owing to the remarkable ease and simplicity of its actual working.

Mr. Edward B. Marten had often seen the machines at work, but generally upon a homogeneous material. He should be glad therefore to know how they would act if they suddenly came upon a boulder. That appeared to him to be the greatest difficulty likely to occur. When cutting in a rather soft soil, and coming suddenly on a very hard and rough rock, what would the machine do?

Mr. Joseph Adamson had seen the machine at work at Coble Dene dock, Tynemouth, and when it came to a boulder it simply tore it out and turned it into the wagon, which he supposed was what it was intended to do. He had also watched the machine at work in the Northumberland dock at Newcastle, where it was certainly working, as the author had said, like a mechanical toy in respect of ease and simplicity.

Mr. Robert S. Boyer said, although he had had no personal experience in connection with this machine, he had seen it at work at Penarth in stiff clay, and it certainly worked exceedingly well. When it came to a boulder, it went on with the cut without any difficulty, and fetched it out: unless of course the boulder was too large, when it would bring the machine up.

Mr. T. Hurry Riches said at the Cardiff meeting last summer many of the members had no doubt seen these machines at work at

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Penarth and at the new docks, where they were excavating in marl and blue lias. The mode of working there was to use light charges of dynamite to shake the rock, and then the navvy tore it out. The machine worked satisfactorily in every instance. He had seen it pulled up by taking too deep a cut and so getting too much to do; but that was the fault of the man in keeping it too close to its work. In his own experience the work had been done in a very satisfactory manner. The only material he had seen the machine working in was blue lias, red marl, and blue clay.

Mr. R. Price-Williams could not but express his great admiration of such a labour-saving machine as that just described; for he remembered how, when the Lancaster and Carlisle line was being constructed many years ago, the price for excavating loose stuff was fourteen pence per yard; and in recent estimates which he had prepared for a railway near London the price for excavating the London clay was also fourteen pence per yard. Contrasting that with the prices mentioned in the paper, the important economy of the steam navvy would at once be realised. He could only regret that the machine had not been available for the deep clay cuttings through which London was approached by the North Western and indeed by all the principal railways having their termini in London. Had such an economiser of labour been in use at the time those cuttings were excavated, a very large sum would have been saved. In this country the greater part of the railway system was now completed; but there was still a great future he believed for the steam navvy in the construction of railways yet to be made, particularly near London, the London clay being a material for which the machine was especially suitable. It would also be useful in excavating docks and canals. It was easy to see that the economy to be obtained by its employment in the construction of a large work like the Manchester Ship Canal would be very great indeed.

Mr. Benjamin Walker said that from the description given in the paper he should be led from a mechanical point of view to expect great success for the steam navvy. Though not having had

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(Mr. Benjamin Walker.)

the good fortune to see the machine at work, the evidence of those who had seen it was a sufficient guarantee of its excellence. Lincoln he trusted would become as famous for the manufacture of steam navvies as it had already become for that of portable engines. The mechanical engineers of the country could not have come to a place where more good work had been done in the manufacture of portable engines than had been done at Lincoln. Certainly the original manufacture started by Mr. Clayton and his partner, the late Mr. Shuttleworth, had done immense service in this district. That firm had been the first to begin the work which had been so successfully carried out. He well remembered being told by them some thirty-three years ago that they intended to make the best and cheapest portable engine, and that they intended to make it so well and so cheap that it should be sure to be bought in large numbers. They considered that to be a sufficient problem for them to solve—to do the work well and cheap. Such an aim could not be too much kept in mind in the present days of bad trade. Mechanical engineers in this country, having to compete with all the world, would do well to follow the example of Messrs. Clayton and Shuttleworth by taking up a certain section of work and doing it so well and at so low a price that no one could compete with them; and then they would be sure to get work. They had now also the further example afforded by Mr. Ruston, who had certainly worked out the steam navvy with an ability which no one could question.

Mr. Joseph Tomlinson had seen the navvy at work, and it certainly did work admirably. Nothing seemed to stop it, except, as Mr. Riches had said, when it was pulled up by giving it too much to do. It did everything that the author said it did, and was managed with such ease that it might truly be called a mechanical toy of very huge dimensions; and it did a huge amount of work.

Mr. Sydney F. Walker had seen these navvies at different places, and had been much struck with the beautiful way in which they did their work. It had occurred to him that the cost and weight might be reduced, if the machine were worked by electro-motors by means

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of wires. In most large contracts it was necessary to have large fitting shops, requiring large boilers and engines; and it would be a simple matter to drive a generator, and from it to carry wires of a comparatively small size to where the navvy had to be employed. That plan would get rid of the weight of the boiler on the navvy, a large portion of the weight of the engine, and the weight of the water tank; and there would not be the trouble of supplying the navvy with coal and water. It was true that the weight of the boiler and engine and water-tank acted as a counter-balance; but he presumed these could be replaced by other dead weights, if it could be shown to be an advantage to work the machine by electricity; and such a plan would get rid of the fireman's wages and other similar expenses.

Sir James N. Douglass had had the opportunity of witnessing the machine in operation at the Coble Dene dock, where he knew it had given great satisfaction to the engineer, Mr. Messent. He had been particularly struck with the excellent and complete way in which it did its work; its automatic performance was simply perfect. A good horse wanted a good rider; and this machine, however perfect and complete in itself, certainly required a good driver. On some occasions he had noticed that the bucket had been overloaded and overstrained, as had been referred to, and there was a slight halt; but there never appeared to be a complete stoppage. On other occasions the bucket was not quite filled; but that was only due to the imperfection of the driver's management at the time. He could easily understand that an expert driver could work the machine so well as to fill the bucket completely; and not only fill it completely, but, which was another very important matter, completely tip it into the wagon without any spilling. The way in which the stuff was put into the wagon he considered a most complete operation.

Mr. Ruston in reply said that, in carrying out this machine from its earliest inception, the great object he had kept in view had been to adapt it to every kind of material which such a machine might be expected to have to excavate. The first difficult material that it had had to deal with had been encountered a short time after

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(Mr. Ruston.)

the original construction of the machine, and was on the line of the Midland Railway passing by Melton to Nottingham. There the material was found to be a homogeneous clay, but exceedingly hard; and it was being excavated during a dry baking summer which rendered the clay so hard that the men working by hand could not get their pickaxes more than an inch or an inch and a half into it. At that time the jib carrying the bucket was found to be too light, and in one or two of the navvies it was crumpled up, simply because the engine had more power than the other parts of the machine; but when those parts were strengthened, and the bucket was driven properly, it cut the homogeneous clay which defied the pickaxe, and dug it out as cheese was cut with a cheese knife.

Another machine, sent to work somewhere between Hartlepool and Darlington for the North Eastern Railway, met with a sort of conglomerate, in which certain stones were imbedded as if set with Roman cement. There for the first time the heavy steel picks on the bucket were adopted (Fig. 5, Plate 39). These of course were not needed for clay, which, however hard, was a homogeneous material; but by their adoption the difficulty with the conglomerate was perfectly overcome, all the parts of the machine being made of the necessary strength. Afterwards some of the navvies were sent to Greenock, where new docks were being made; and there they excavated the boulder clay, in which occurred stones of a very much larger size. The opportune question asked by Mr. Marten related to one of the crucial points in the problem that had to be solved. When a boulder or block of stone was found, too large for the bucket to grasp and deal with, the wheelman by easing his footbrake allowed the bucket to fall back from the cut it was taking and to clear itself from the face of the bank. In this way a boulder or a reef of rock which the bucket could not cut through could be undercut by degrees, until it overhung far enough to be broken down or to break down of itself. In that way all difficulty was overcome, and all risk of injury to the machine was avoided. The one great thing that was essential in all cases was to make the engine the weakest part of the machine, so that when the cutting became too severe for it the engine should be pulled up without any harm being done.

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With respect to electro-motors, if it should be found that electrical power could be applied to work the navvy much more economically and efficiently than steam, then he imagined it would be applied; but for practical purposes he had always found steam sufficient. The weight of the engine and boiler and water-tank, as had been remarked, was wanted for the stability of the machine in working; but of course that stability could be obtained by loading with pig-iron just as well as with a costly engine.

At Boston, where a new outfall for the river Witham had been made, exceeding in section the Suez canal, three navvies worked abreast, excavating the cutting at a very rapid rate.

With regard to the remark made by Sir James Douglass, it was precisely the fact that the speed and efficiency of the machine depended altogether upon the skill of the two men who were working it. The driver standing beside the engine, who put the clutches in and out of gear, was generally a skilled mechanic; the wheelman, acting under the driver's orders and in concert with him, was generally a contractor's labourer who in a fortnight became practically competent for everything he ought to do in working the machine.

The President said the steam navvy appeared to him to be a machine having characteristics of a special kind. There was not much difficulty in performing the usual operations of mechanical engineering, if only a fixed and substantial base or fulcrum was available to work from. But here was a case where very great force was exerted, and yet where there was only a shifting or movable base to work from. That was one of the chief peculiarities in the present instance, and he thought the difficulty had been surmounted with remarkable ability. A somewhat analogous case was that of steam ploughing, where the plough offered at times great resistance, and the fulcrum was an engine which also moved along the headland. But the resistance in the case of the navvy was much greater than in the case of steam ploughing; perhaps steam draining came nearer to it. As in the case of steam ploughing or steam draining, the greater the resistance offered by the soil, the greater was the advantage of steam machinery over human or animal labour. In fact in steam

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(The President.)

ploughing and steam draining, when a certain depth or a certain toughness of soil was exceeded, the work was such that it could not be done by animal power at all. This seemed to be the case also with the navvy. The machine was able not only to do work cheaper than by hand, in proportion to the difficulties surmounted, but also to do work that could not be done at all by unaided labour.

The interesting paper just read was one of which any Institution might be proud; and he asked the members to join in according a very hearty vote of thanks to the author for it.

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SEMI-PORTABLE ENGINE.

Plate 43.

20 H.P. *Semi-portable Winding and Pumping Engine.*

Fig. 1. *End Elevation.*

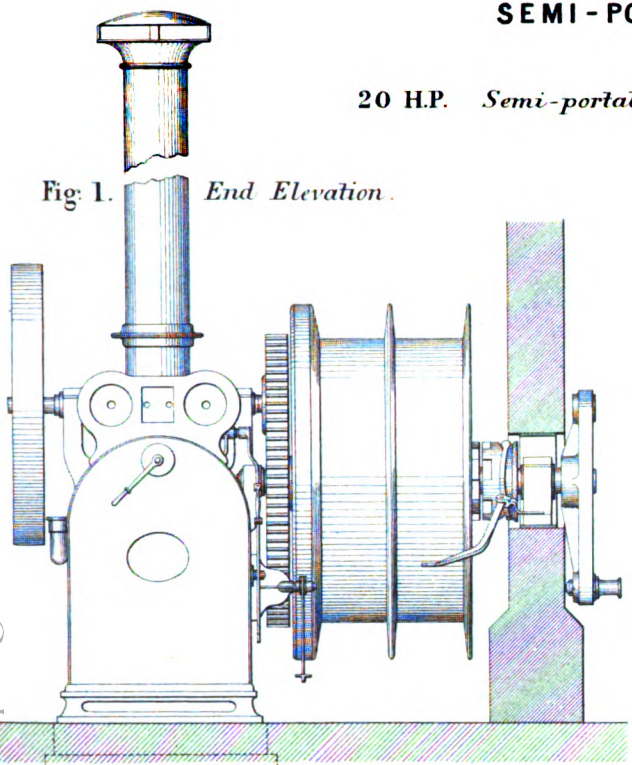
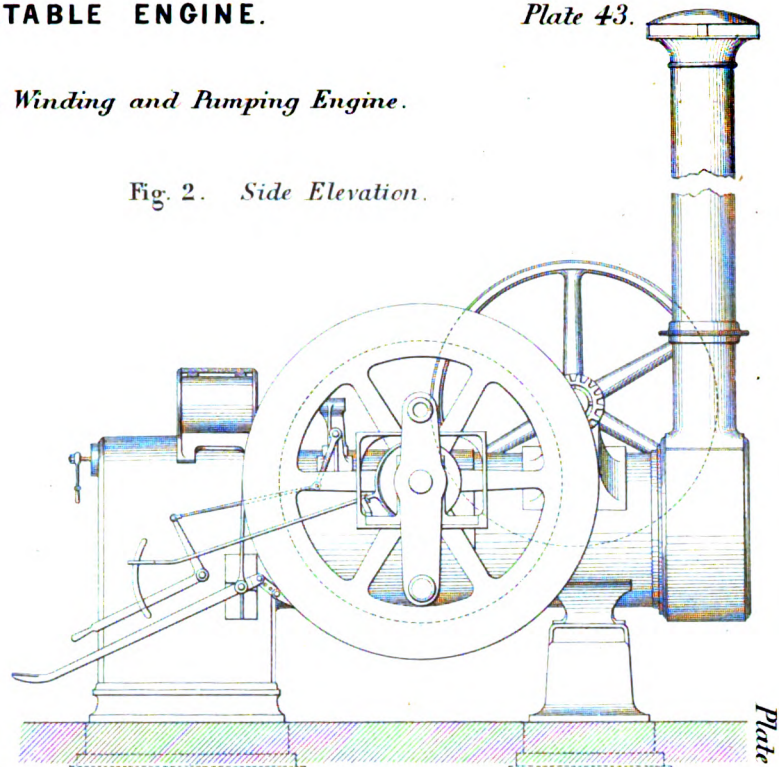


Fig. 2. *Side Elevation.*



(Proceedings Inst. M.E. 1885.)

Scale 1/50th

0 5 10 15 Feet.

Plate 43.

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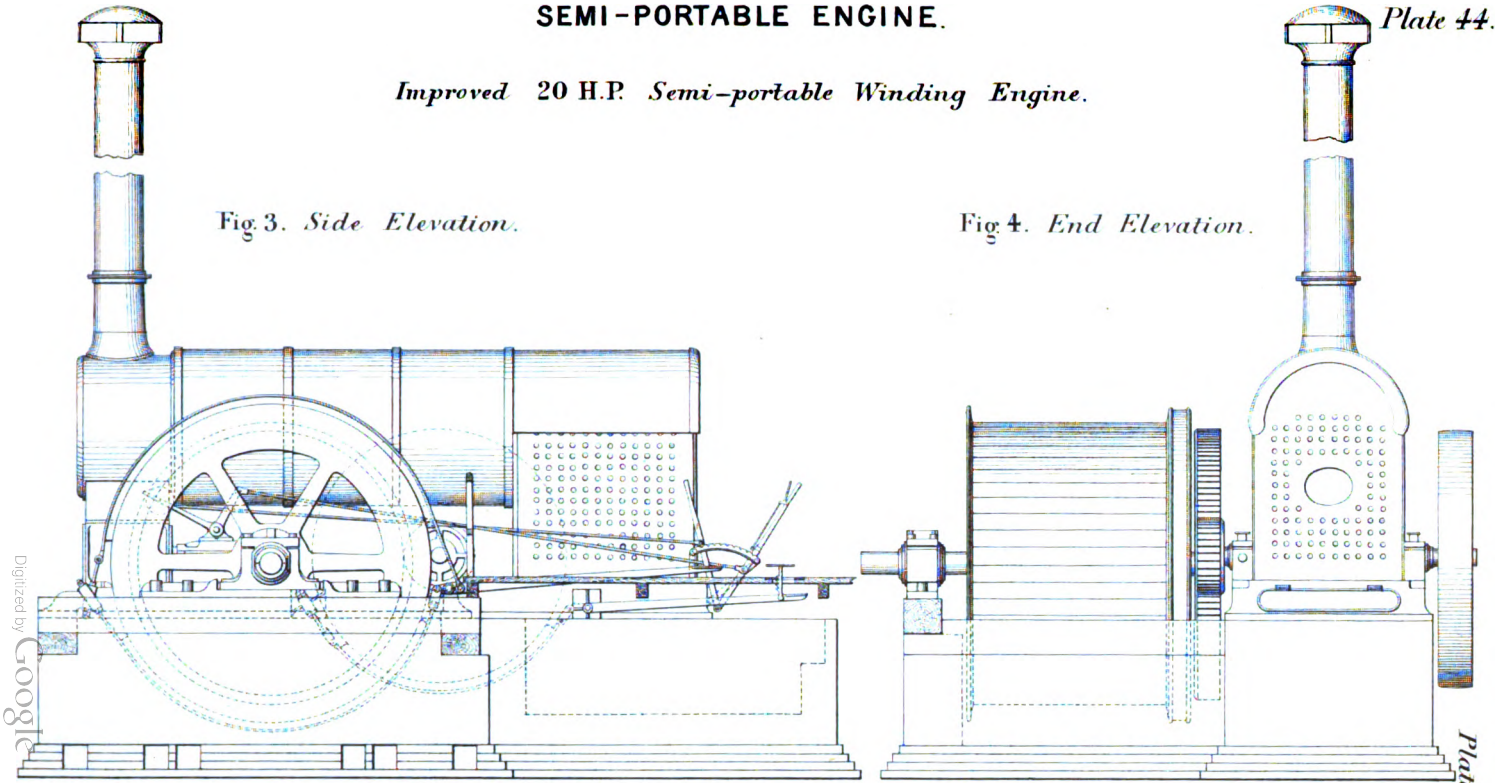
SEMI-PORTABLE ENGINE.

Improved 20 H.P. *Semi-portable Winding Engine.*

Fig. 3. *Side Elevation.*

Fig. 4. *End Elevation.*



(Proceedings Inst. M.E. 1885.) *Scale 1/70 th*

0 5 10 15 20 Feet.

Plate 44.

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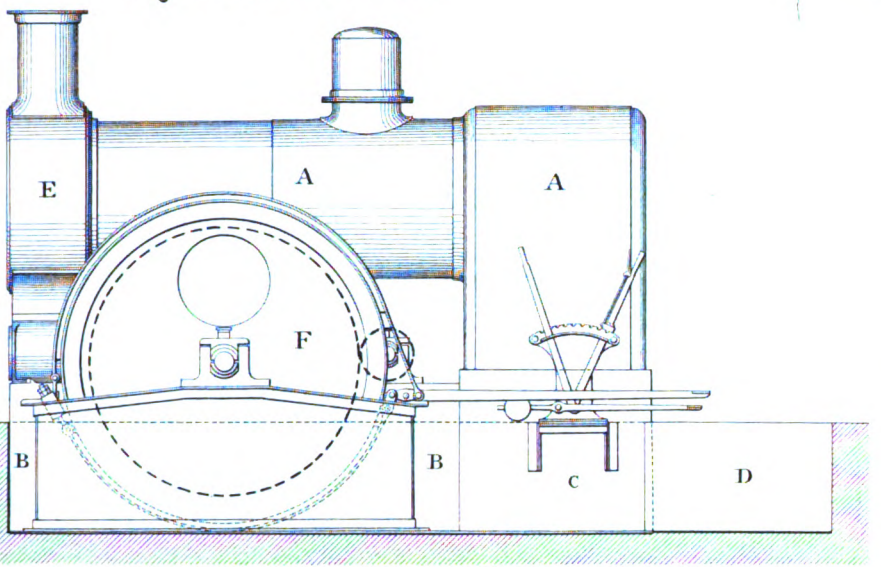
SEMI-PORTABLE ENGINE

Plate 45.

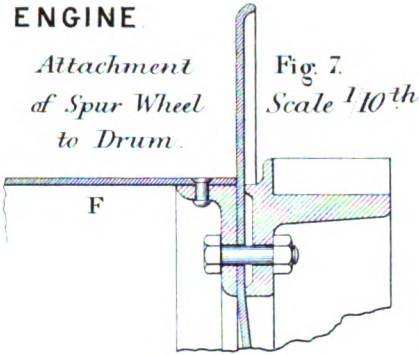
Semi-portable Winding Engine with wrought-iron foundations.

Fig. 5. *Side Elevation.*



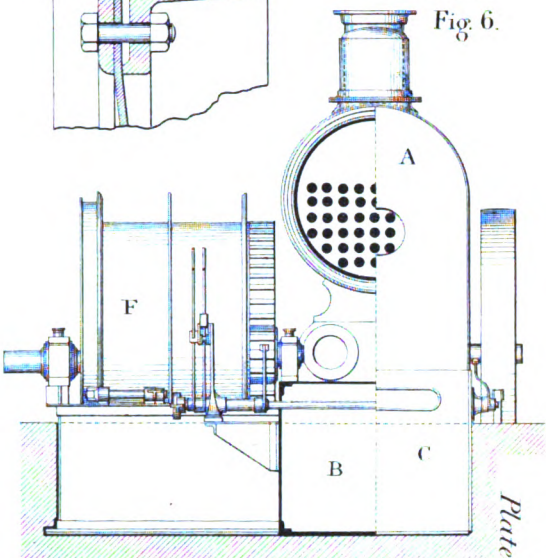
Attachment of Spur Wheel to Drum.

Fig. 7. *Scale 1/10th*



End Elevation.

Fig. 6.



(Proceedings Inst. M.E. 1885.) *Scale 1/50th*

Plate 45.

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SEMI-PORTABLE ENGINE.

Plate 46.

Engine packed for transport.

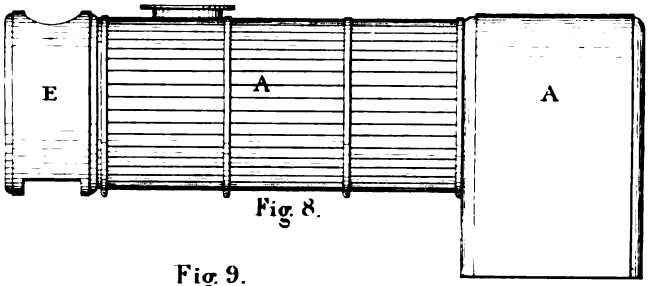


Fig. 8.

Fig. 9.

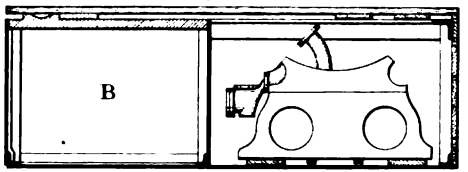


Fig. 10.

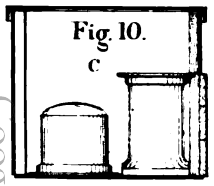
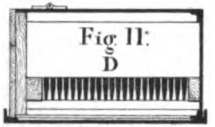


Fig. 11.



(Proceedings Inst M.E 1885.)

Scale 1/50th

0 5 10 Feet.

40-H.P. *Compound Condensing Engine.*

Fig. 12. *End Elevation. Scale 1/30th*

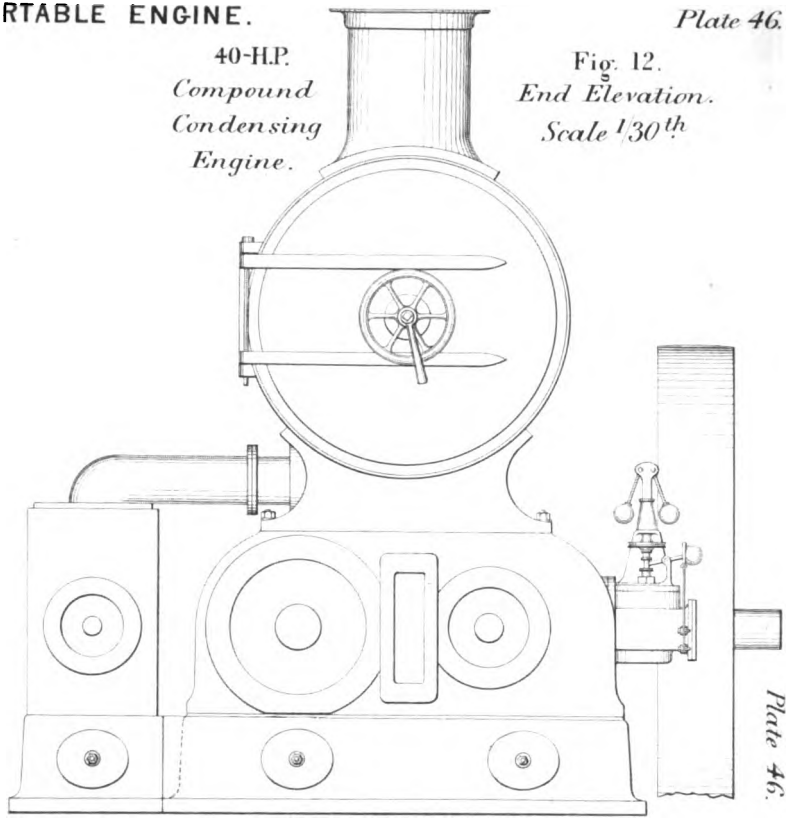


Plate 46.

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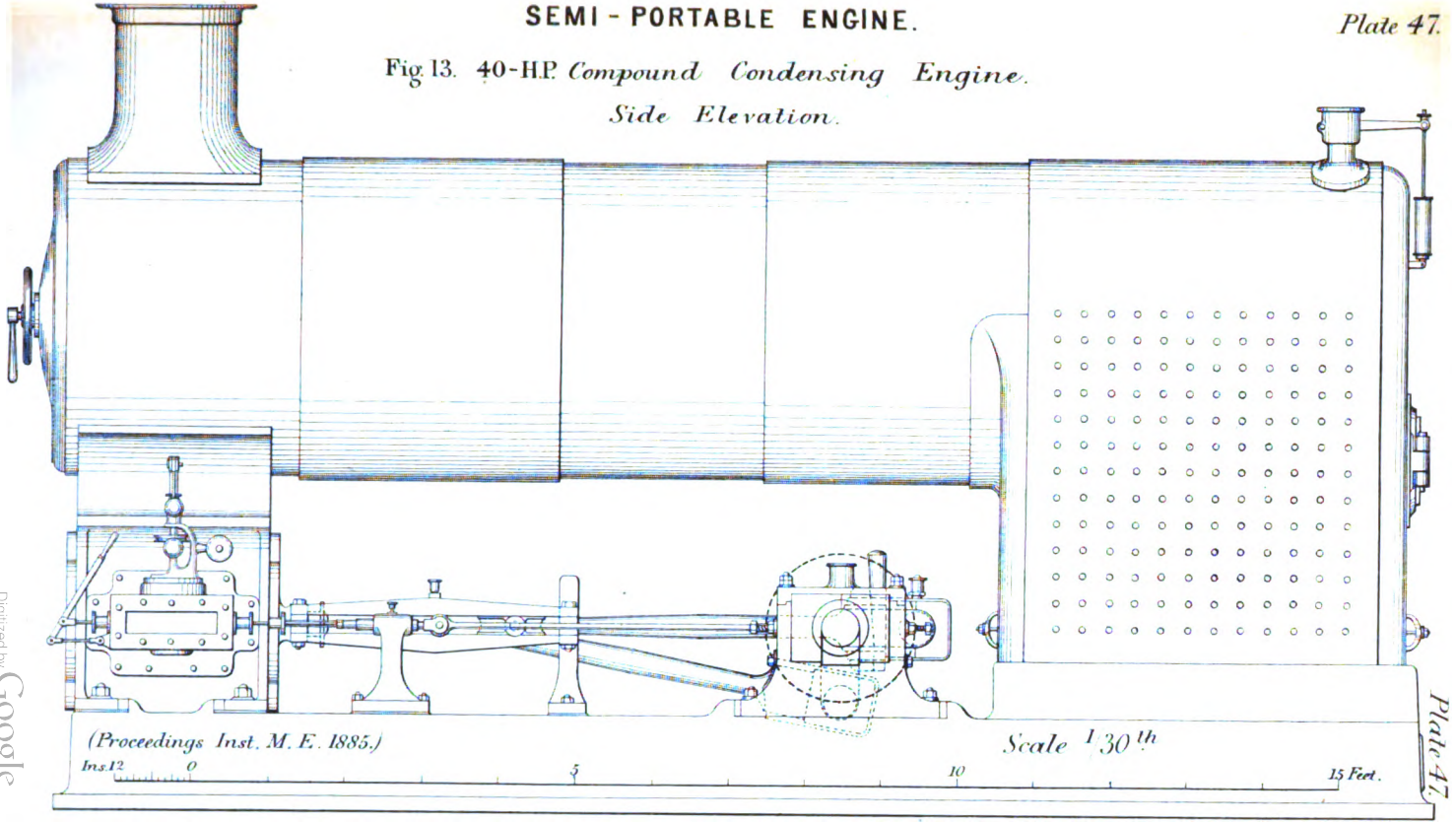
SEMI-PORTABLE ENGINE.

Plate 47.

Fig. 13. 40-H.P. *Compound Condensing Engine.*

Side Elevation.



(Proceedings Inst. M. E. 1885.)

Scale 1/30th

Ins. 12 0 5 10 15 Feet.

Plate 47.

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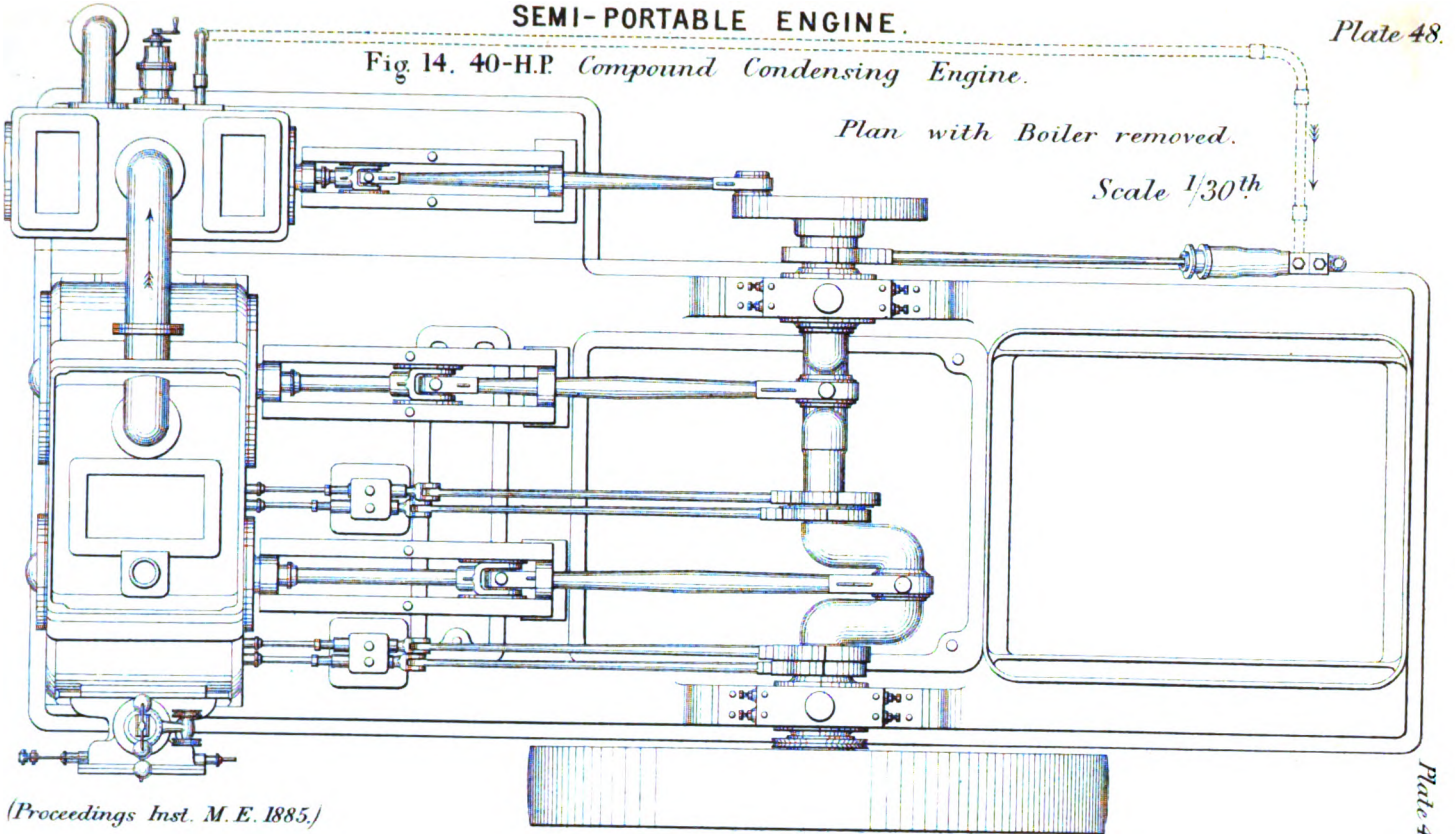
SEMI-PORTABLE ENGINE.

Fig. 14. 40-H.P. *Compound Condensing Engine.*

Plan with Boiler removed.

Scale 1/30th



(Proceedings Inst. M.E. 1885.)

Plate 48.

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Fig. 15.

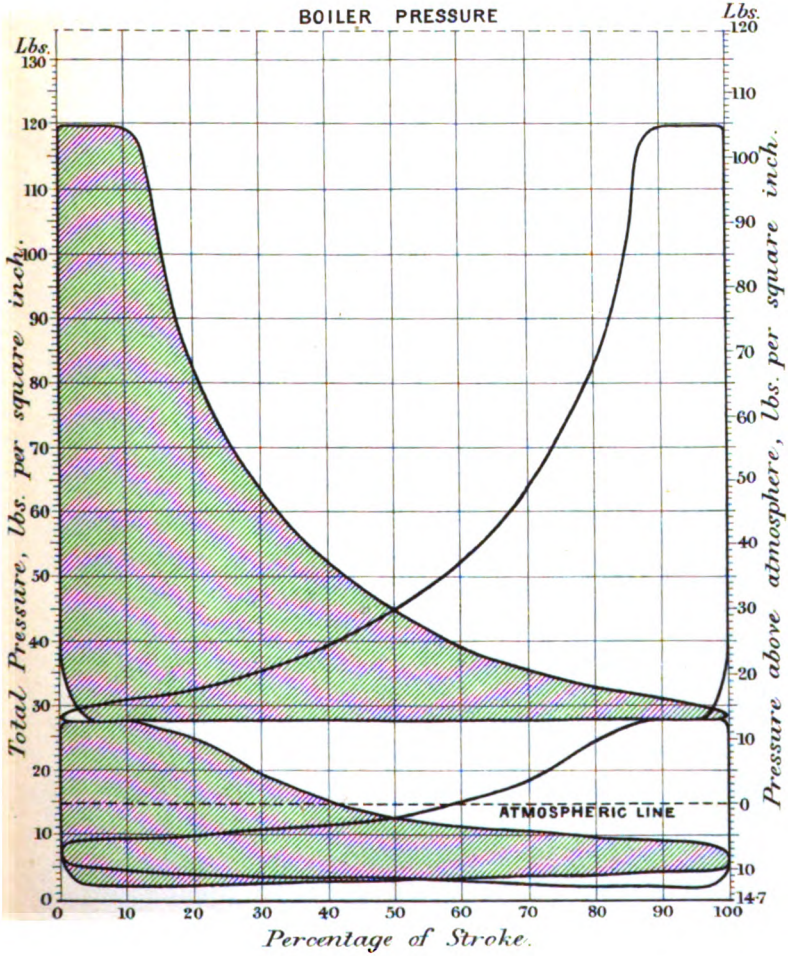
Indicator Diagrams

from Compound Semi-Portable Engine.

High-pressure Cylinder ... 12 *inches diameter.*

Low-pressure Cylinder ... 21 *inches diameter.*

2 *feet stroke.* 90 *revs. per min.* 90 *Horse power.*



(Proceedings Inst. M. E. 1885.)

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ON RECENT ADAPTATIONS OF THE ROBEY SEMI-PORTABLE ENGINE.

By Mr. JOHN RICHARDSON, of Lincoln.

Portable Engine.—On the occasion of the Summer Meeting of the Institution at Penzance in 1873 (Proceedings, page 167) the author had the pleasure of reading a paper on the application of Portable Engines for mining purposes, a number of engines of Messrs. Robey's manufacture being then successfully at work in Cornwall and elsewhere. The subject attracted considerable attention among the Cornish miners and engineers, and the use of such engines for mining work has since then rapidly extended, and their horse-power considerably increased. Up to that time these engines had seldom been made over 25 HP. nominal; but within two years of that date a number of them were in use having a pair of cylinders of 16 inches diameter and 24 inches stroke, developing easily 150 HP., and constructed as represented in Figs. 1 and 2, Plate 43.

Semi-Portable Engine.—It was while engaged in the construction of these large semi-portable engines with their powerful gear that the author conceived the idea of making that radical change in their construction, which resulted in what is now so well known as the Robey Semi-Portable Engine, of which the first designed and made was that represented in Figs. 3 and 4, Plate 44. All the main features of this first engine have since been adhered to, while sundry improvements in detail have been introduced from time to time.

The engine, as will be seen, is erected on a massive cast-iron foundation plate, to which all the working parts are fixed, together with one of the drum-shaft bearings, and the brackets for carrying the brake-straps and levers. The whole of the strains due to the working of the machinery are contained within the base plate, and

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Very much more remains to be said as to the relative advantages of iron and steel for different purposes. But your patience and my time must by this time be fully exhausted. The conclusion we may fairly come to is, I think, that the sudden and complete revolutions, so frequently prophesied by those who jump to conclusions from superficial appearances, occur no more in the arts than in nature. The laws of gradual change, and of the survival of the fittest, apply equally in both cases. Steel soon proved itself superior to iron for rails and tyres, and complete supersession followed. In other departments, such as guns and marine boilers, similar causes have produced similar results. But where circumstances differ materially, so do consequences. Wrought-iron still preponderates in the heavy forge, the blacksmith's shop, the bridge and roof-building yard, and the agricultural implement factory. Though steel castings are of exceeding value for special purposes, there is no probability whatever that they will ever supersede iron ones generally. And with regard to ships, it may be said that though a steel ship is better than an iron one if built to the same scantlings, it is doubtful if it is equal to it when built substantially thinner. But whatever our present views may be on these important questions, we may rest assured that in the long run the fittest material will prevail, according to the peculiarities and necessities of each particular case.

It now only remains for me to thank you for the patience and courtesy with which you have listened to this somewhat lengthy, and, I fear, very imperfect address.

The PRESIDENT said that since the completion of his address he had received additional information which had to some extent modified the views he had therein expressed. In the first place he had

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been informed by Mr. Parker, Lloyd's chief engineer surveyor, that their tests had recently been altered in an upward direction. For instance, instead of from 27 to 31 tons per square inch, the range for the tensile strength of steel had been raised to from 28 to 32 tons. In the second place he had sent a copy of the address beforehand to Mr. Parker and to Mr. Martell, Lloyd's chief surveyor, asking them to be kind enough to criticise it; and they had accordingly done so. Of course from their great and exceptional experience they were able to throw additional light on some points which had perplexed him, and generally to give additional information of considerable value. He had not yet had time to consider their comments; but as soon as the work of the present meeting was over it was his intention to do so, and to add in an appendix such remarks as might seem to be necessary. It would therefore be understood that the section relating to steel and iron shipbuilding must be taken as subject to such corrections as he might make in the appendix (see pages 347–8).

With regard to steel castings, it would be observed that he had said that all steel castings must be annealed. Since completing the address he had ascertained that at some steel foundries annealing was being dispensed with occasionally, that is in the case of castings for certain special purposes.

The specimens referred to in the address were on the table for the inspection of the meeting. They included pieces of iron and of steel fencing-wire which had been subject to similar atmospheric conditions in two localities, as explained in the address (p. 341); the steel in each case was much more deeply corroded than the iron. There were also samples showing the peculiar brittleness of steel when worked at a straw colour and blue temperature (p. 337).

The MAYOR OF LINCOLN said it was his pleasing duty to propose that the best thanks of the Institution be given to the President for his able interesting and instructive address. He felt sure that every one who had listened to it attentively could come to no other conclusion than that steel for many purposes was far superior to iron. He had been greatly struck with the suggestion that steel

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(The Mayor.)

should be used instead of wood for sleepers. It appeared to him however that that would be false economy unless there were an inexhaustible supply of a common ore which might be used for railway sleepers; otherwise a material which could not be reproduced would be used up for replacing one which could be. The one could be grown, but not the other. But this was a matter for other consideration than his own.

Mr. CLAYTON said he had great pleasure in seconding the resolution proposed by the Mayor. He was sure they all felt greatly obliged to the President for his admirable address. For himself he had been greatly instructed by it, and felt sorry when it came to a conclusion.

The vote of thanks was cordially passed to the President for his Address.

The PRESIDENT, in acknowledging the vote of thanks, said he had only to add that his sole object in investigating the matters dealt with in his address had been as far as possible to find out and circulate the truth. If in any matters he should be found to have been mistaken, he should be quite as anxious to make the necessary corrections as those who were good enough to point out errors.

APPENDIX TO THE PRESIDENT'S ADDRESS.

The criticisms upon my address, which Messrs. Martell and Parker, of Lloyd's Register, were so good as to hand to me, but not in time for consideration at the Lincoln meeting, are substantially the following:—

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1st. They admit that ship-plates, regarded as broad girders, and strained upon the flat, will sustain loads proportionate to the square of their thickness. But they contend that the plates forming the shell of a ship's hull are not so strained in actual work. They think that a ship should be regarded as a large box-girder; and that, whether in traversing the waves she is supported mainly at the ends or mainly in the middle, the resulting stresses in the upper and lower members of the girder (or portions of the shell corresponding thereto) are purely tensile, or purely compressive. They contend that, so regarded, the strength of the plating varies directly as its thickness, and not as the square thereof. And they consider that the internal framework of a ship is sufficient to maintain the form of the shell, and to keep the plating in line under the ordinary stresses encountered at sea.

My reply to the above criticism is, that I admit fully all contended for, except that it appears to me that the plates forming the shell of a ship may nevertheless be sometimes strained as flat girders. Thus when a ship is moving along a quay wall, or past another ship, with a fender (say a wooden roller) between, the plates will be apt to be bent inwards between each frame, with a facility varying inversely with the square of their thickness. Perhaps the case quoted in page 316 of the address may have arisen in this way. Also it seems to me that contact with icebergs, rocks, wreckage, or muddy bottoms, may at times produce local pressure upon portions of the plating of a ship, in such a way as to render the stiffness due to thickness an important factor in resisting local change of form.

2nd. Messrs. Martell and Parker state unhesitatingly that no steel ship built to the *present* steel scantlings of Lloyd's rules has been found to exhibit symptoms of structural weakness. They affirm exactly the same of iron ships, built to iron scantlings. They admit that cases of weakness have from time to time been reported; but when investigated these have invariably been found to have resulted from errors or deviations for which their officials were not responsible, or from careless stowage of heavy cargo, or from other negligence.

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These statements relate entirely to matters of fact which Lloyd's officials have observed and recorded. Outsiders can only congratulate the Committee that their accumulated experience enables them now to specify with certainty how to build a perfectly strong and satisfactory vessel either of steel or of iron.

3rd. Messrs. Martell and Parker say that, if the use of steel of a lower tensile strength than is prescribed by Lloyd's rules, combined with proportionately increased scantlings, is not permitted, it is simply because no such permission has ever been sought for. They concur in the opinion I have expressed in page 317, that a ship built of 24 or even 22-ton tested steel would be superior to an iron one of similar scantlings; and they are sure that any proposal to put this idea in practice will receive the most favourable consideration from their Committee.

I regard this declaration as of considerable importance, and am glad that my address has had the effect of eliciting it; not only because it is a matter of interest to mechanical engineers, but also because it may have an important bearing on the future of the iron, steel, and shipbuilding industries.

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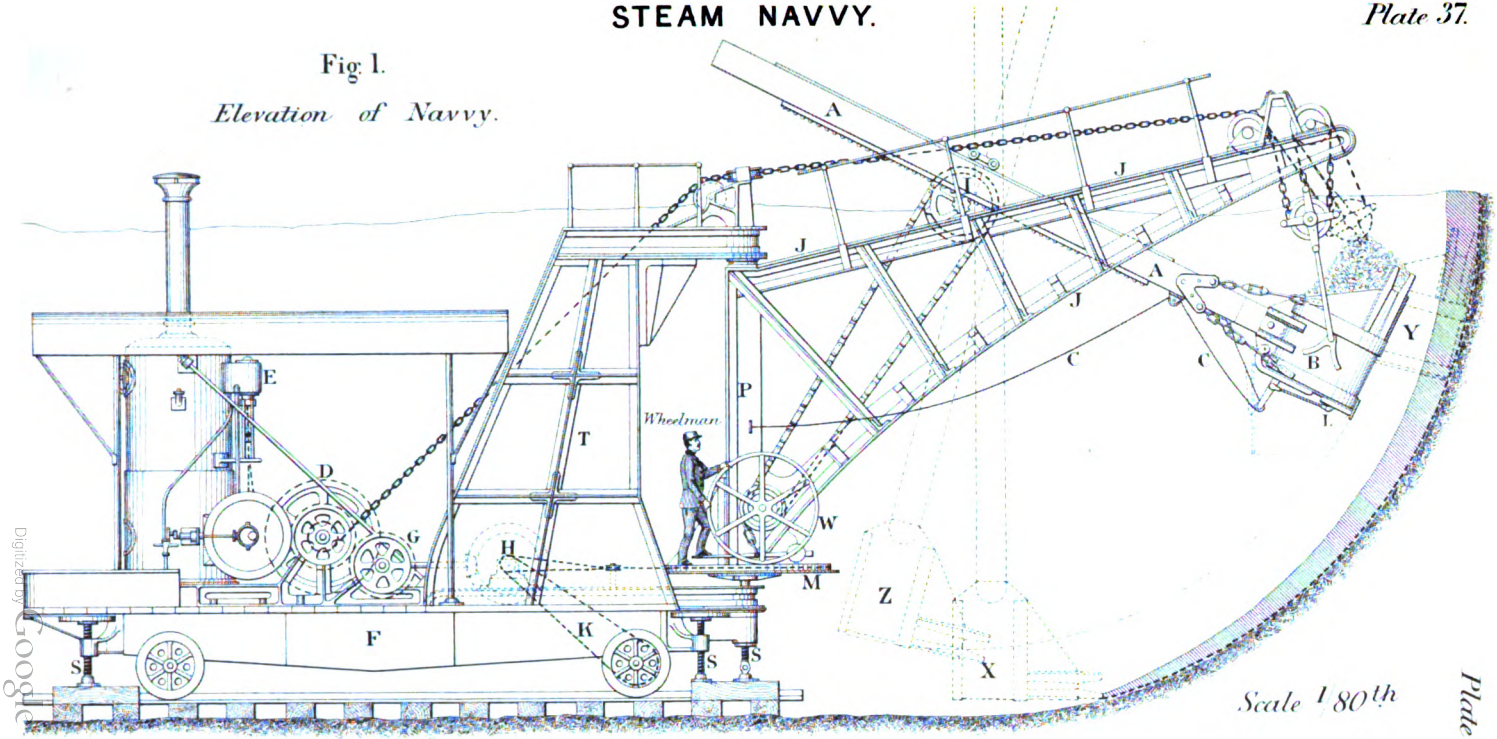
STEAM NAVVY.

Plate 37.

Fig. 1.

Elevation of Navvy.



(Proceedings Inst. M.E. 1885.)

Plate 37.

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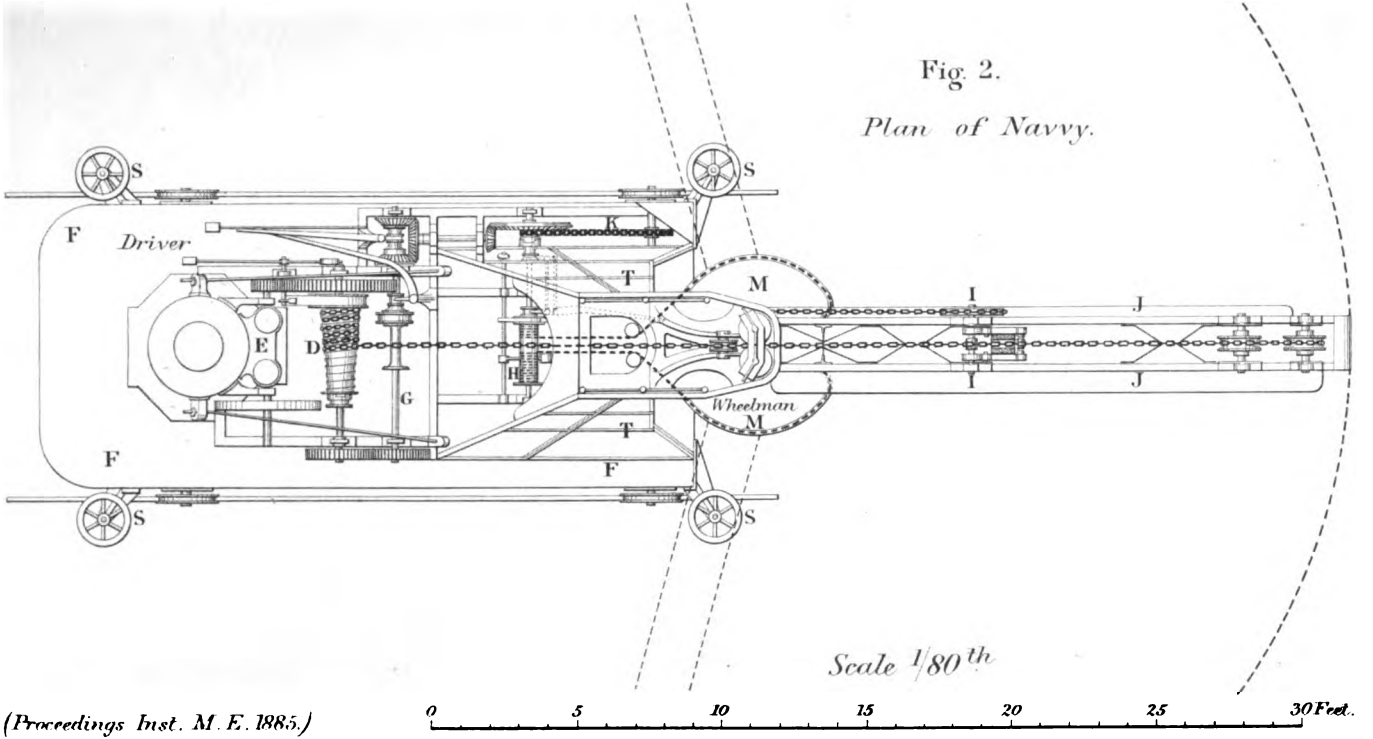

Fig. 2.

Plan of Navvy.

Scale 1/80th

(Proceedings Inst. M. E. 1885.)

Plate 38.

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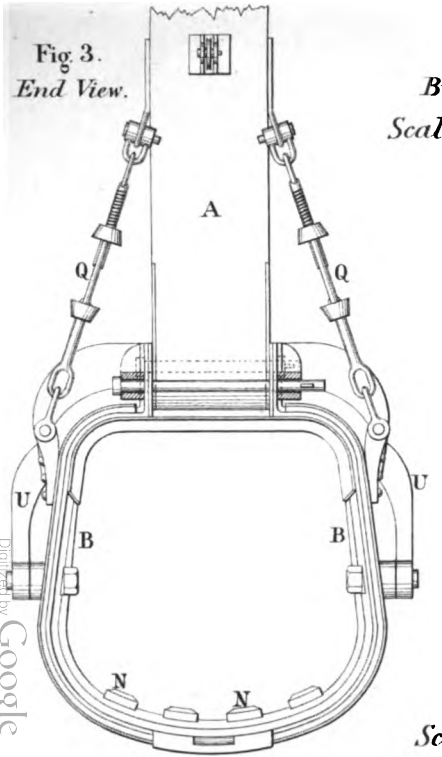
STEAM NAVVY.

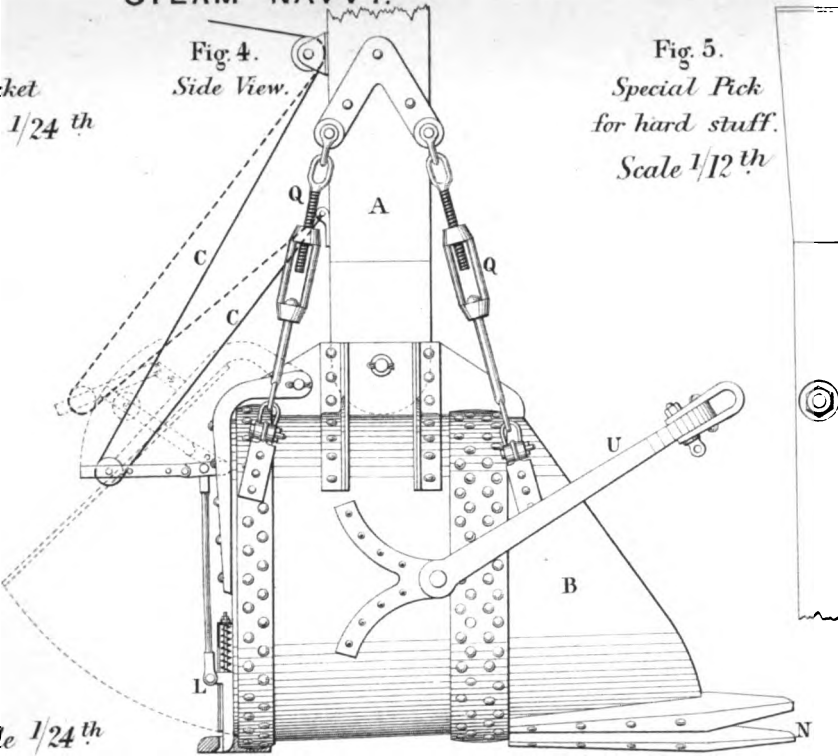
Plate 39.

Fig. 3.
End View.



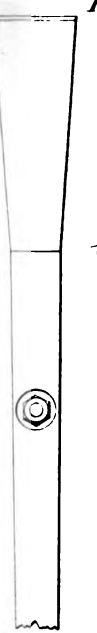
Bucket
Scale 1/24 th

Fig. 4.
Side View.



Scale 1/24 th

Fig. 5.
Special Pick for hard stuff.
Scale 1/12 th



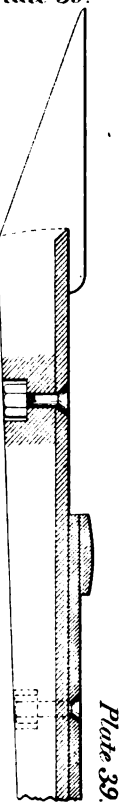


Plate 39.

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(Proceedings Inst. M. E. 1885.)

Ins. 12 6 0 1 2 3 4 5 6 Feet.

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Fig. 6.
Plan.

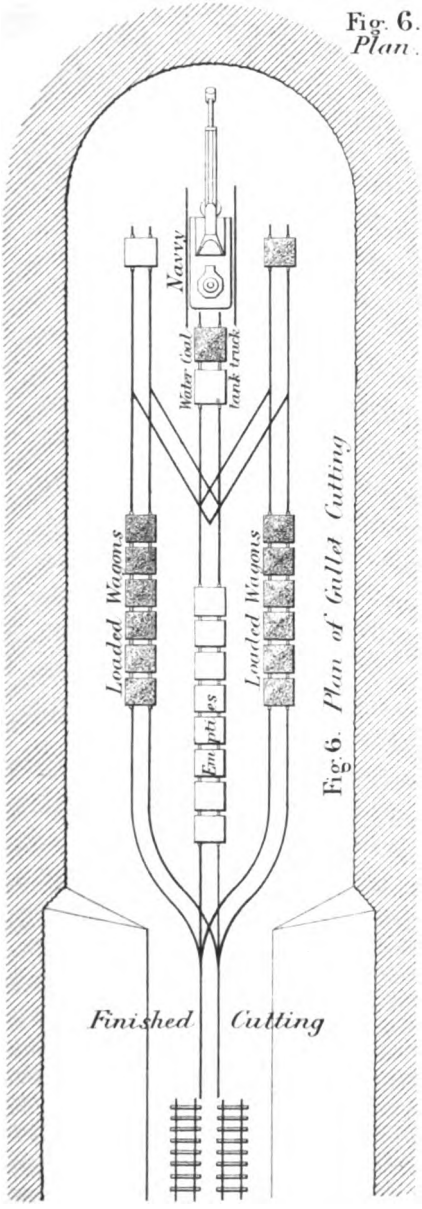


Fig. 6. Plan of Gullet Cutting

Fig. 8.
Plan.

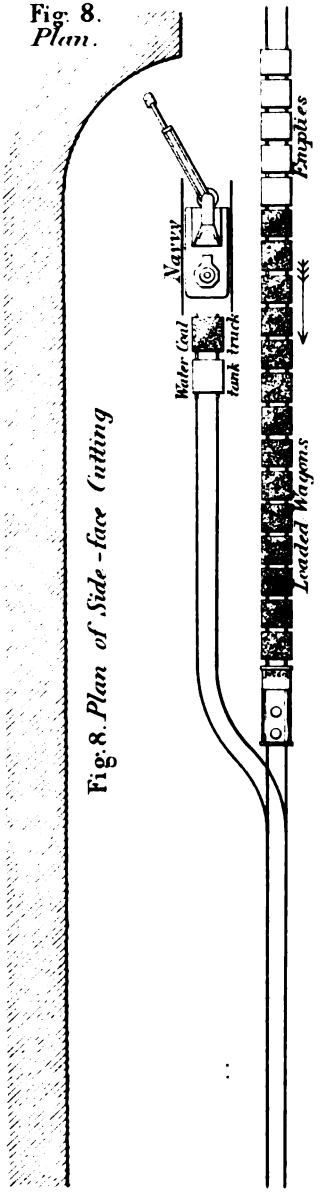
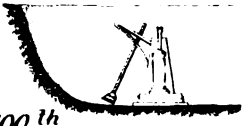


Fig. 8. Plan of Side-face Cutting

Gullet Cutting.
Fig. 7. Section.

Side-face Cutting.
Fig. 9. Section.



(Proceedings Inst. M.E. 1885.)

Scale 1/600th

10 0 50 100 150 Feet.

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STEAM NAVVY.

Plate 41.

Fig 10. *Double-line Railway Cutting, 25 feet deep. Taken out by one gullet, with double road to Navvy.*

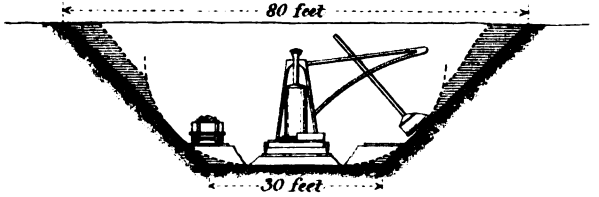


Fig 11. *Double-line Railway Cutting, 50 feet deep. Taken out by three gullets, with double road to Navvy.*

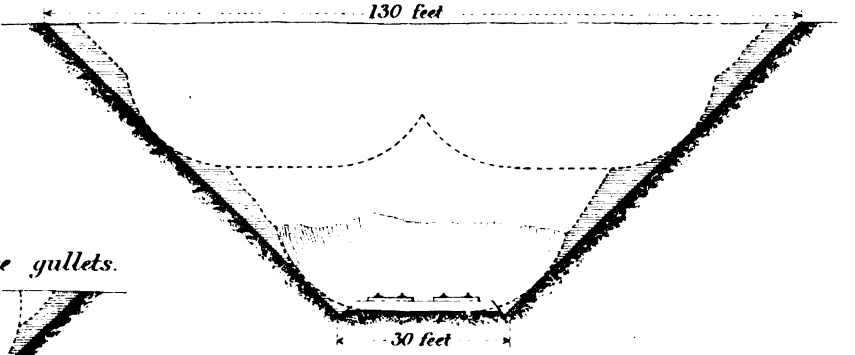


Fig 13. *Canal, 20 feet deep, taken out by three gullets.*

Fig 12. *Single-line Railway Cutting, 25 feet deep. Single road to Navvy.*

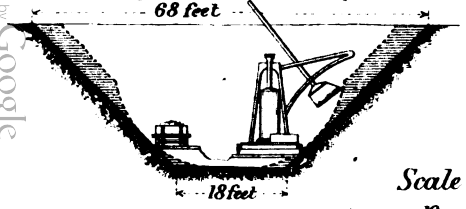
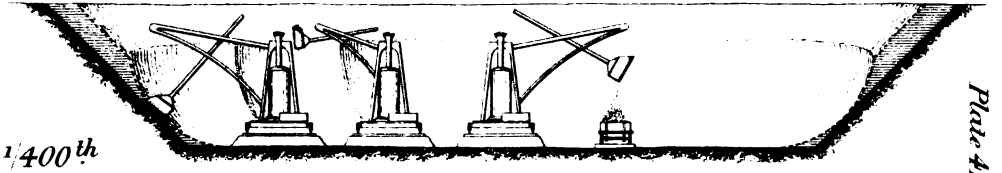


Fig 14. *Dock Cutting, 25 feet deep. Double road in gullet, single roads to side cuts.*



Scale 1/400th

10 0 50 100 150 Feet

(Proceedings Inst. M. E. 1885.)

Plate 41.

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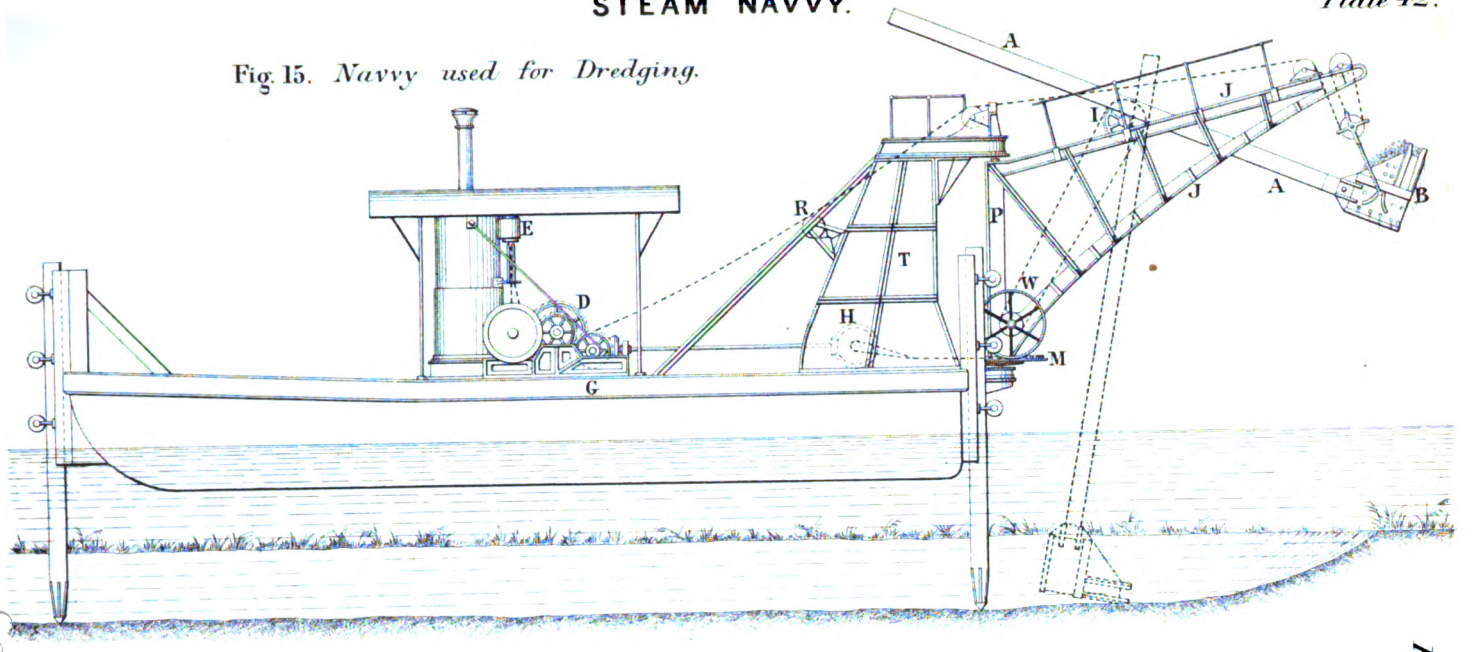
STEAM NAVVY.

Fig. 15. *Navvy used for Dredging.*



(Proceedings Inst. M.E. 1885.)

Scale 1/130 th

0 10 20 30 40 50 60 70 Feet.

Plate 42.

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DESCRIPTION OF DUNBAR AND RUSTON'S STEAM NAVVY.

By Mr. JOSEPH RUSTON, M.P., of Lincoln.

In the large excavations constantly being made for railways, docks, canals, and other engineering works, containing often many hundreds of thousands of cubic yards, a substitute for the pick and spade has long been sought, and various mechanical contrivances have from time to time been adopted with more or less success. The problem may however be considered to be now solved by the Steam Navvy forming the subject of the present paper, which is believed by the writer to be perhaps the most successful machine yet introduced for this end, being not merely suitable for one form of digging or for one kind of material, but also capable generally of dealing with every large excavation which contractors are called upon to make, and thus proving itself in fact an expeditious, reliable, and most advantageous help. So successfully has it fulfilled the purpose in view, that its use on all works of any magnitude, at least in this country, is the rule rather than the exception; and its manufacture forms an important branch of the business at the writer's works, from which upwards of a hundred of these machines have now been turned out, the majority for use in Great Britain, and the remainder distributed in various parts of the world. Among the completed works on which it has been employed with special success may be mentioned the following:—Victoria dock, London; Coble Dene dock, Tynemouth; Penarth, Swansea, Silloth, and Greenock docks; new outfall works for the river Witham at Boston; harbour works at Calais, and at Melbourne, Australia; cuttings on the Great Northern and the London & North Western Railways at Melton Mowbray, the Midland Railway at Manton and Bootle, the Dover and Deal Railway at Dover, the Rugby and Northampton, the Paisley, and the Didcot and Southampton Railways, the Lanarkshire

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lines at Airdrie, the North Eastern Railway at Bishop Auckland, the Guildford & Surbiton and the Rhymney Railways; and other works.

The steam navvy excavates and delivers into wagons any material capable of being cut, such as sand, gravel, chalk, and clays of all kinds, digging out with equal facility the hardest and toughest, such as require blasting when worked by hand. It can also deal with these materials when thickly interspersed with stones and heavy boulders; and without being unduly strained it cuts through seams of flints, shale, slate, or even sandstone, which may intersect the face of the excavation it is at work upon. With the assistance of blasting, it is also used with advantage in much more difficult stuff, such as hard marl and lias rock.

Development.—Since its introduction many improvements have been made, increasing its power and efficiency. The framework has been considerably strengthened throughout, augmenting the total weight by several successive increments from 22 tons in the earliest machine to 32 tons, which is now adopted as the standard; the scoop averages a capacity about 25 per cent. larger than at first, and has an increased angular range. The duty has progressed in a greater ratio, nearly 50 per cent. having been added to the original output. At first 180 to 190 wagon loads were considered a good day's work; now 240 to 250 are often obtained, and even more under very favourable conditions: the day consisting of ten hours, and the wagons being the size ordinarily used by contractors, holding 3 cubic yards each, in which however the stuff is more solidly packed by the navvy than when they are loaded by hand. With extra large wagons holding 4 cubic yards each, an equal number has been filled in a day, equivalent to the grand total of nearly 1,000 cubic yards per day.

Construction.—The machine is shown in Figs. 1 and 2, Plates 37 and 38; Fig. 1 being an elevation, and Fig. 2 a plan. It may be described generally as consisting of a strong rectangular wrought-iron frame F mounted on wheels, forming a substantial base to which all the parts are secured. On the back end is placed the

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engine E, beside which the driver stands, Fig. 2. At the front end rises a wrought-iron tower T carrying the top pivot of a crane jib J, the lower pivot resting on girders fixed to the main frame. The jib may be said to be of twin construction, being composed of two sides which are united only at the post P and at the outer end or point; between them therefore is a long slot, in which swings an arm A of adjustable length, depending from a fulcrum fixed on the upper member of the jib; and at the base of the post is a circular platform, on which a man stands to regulate by means of a hand-wheel W the "reach" or length of radius of the arm A. The scoop or bucket B is fixed at the lower end of the arm A, and is raised or lowered by the main chain passing over the extremity of the jib.

Handling.—The whole of the movements are controlled by two men, called the "driver" and the "wheelman." The driver raises the scoop while making its cut, swings it round into position for discharging, and back again afterwards, and lowers it down. The wheelman regulates the depth of the cut, releases the scoop from the face of the bank, and opens the door or bottom for discharging its contents.

Supposing the navvy to be in position, the mode of working is as follows. The bucket having been lowered till its arm is vertical, as shown by the dotted lines at X in the elevation, Fig. 1, Plate 37, the wheelman regulates the length of the arm A by means of his hand-wheel, so that the cutting edge of the bucket shall get its proper grip of the soil. The driver throws the main-chain drum D into gear, and the scoop is dragged forwards and upwards by the chain into the position Y, describing a circular arc of about 80 degrees and cutting out the tapering slice indicated by the lighter shade. By the time it reaches the top it is fully loaded, and the driver throwing the drum out of gear holds it with a footbrake; at the same instant the wheelman by easing his footbrake allows the bucket to fall back to B, clearing itself from the face of the bank. The driver next swings the jib round till the bucket is over the wagon, when the wheelman releases the latch L by means of a cord C, and the door of the bucket falling open, the contents instantly drop through. The driver then

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swings the jib back again, and at the same time lets go the footbrake of the chain drum, thus causing the bucket to descend through a sort of spiral course, until he brings it up sharply by the brake again when in position Z. The wheelman at the same moment adjusts the fall by means of his brake, so as to lower the bucket to X again, with just the right reach of arm for the next cut. During the fall the door of the bucket closes and latches itself automatically by its own weight; and all is then ready for repeating the operation.

Although apparently somewhat complicated when thus performed in combination, the several movements are each very simple; and the whole cycle can be performed in less time than has been taken to describe it. Three quarters of a minute is sufficient for scooping out from 1 to 2½ tons of stuff, according to the capacity of the bucket, for dropping the stuff into the wagon, and for returning the scoop into place ready for another cut.

After the machine has dug out all within reach, the jack-screws S which steady it are eased; and the propelling gear being put in action, it is moved forwards 3 or 4 feet; the screws are then tightened down, and another series of cuts is commenced. The cuts all radiate from the centre round which the jib swings; and they may together form a hole more or less resembling a crater, according to the plan adopted in making the excavation, as shown in Plate 40, which will be described subsequently.

Details of Construction.—Proceeding to the constructive details of the navvy, the main frame F, Plate 37, has its side girders formed deeper in the centre than at the ends; and they are duplicated on each side at the front end under the tower T. There are three internal transverse girders, and longitudinals again under the engine and gearing; all are well tied together, and stiffened by angle-irons and gussets. Between the inner longitudinals under the tower a large tank is formed, which when filled with water acts as ballast to steady the machine, and forms a convenient supply for the engine. The whole frame is riveted together at the works; but to facilitate transport it is divided crossways in the centre, and the two halves are united by bolts and joint plates.

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The lower pivot of the crane post P is carried somewhat in advance of the main frame F by a pair of projecting girders riveted on the top of the transverse members of the frame, and converging in the form of a V to an apex, at which is placed the pivot; these are further stiffened by plates underneath, and the front end of the frame where they are fixed is made of double thickness the whole way across. This construction has been found necessary in order to provide for the enormous stress which has to be resisted at this point if the bucket is allowed to jam itself when cutting; the force is indeed sufficient sometimes to lift the back or engine end of the machine almost off its legs. The plan of carrying the pivot well in advance of the main frame, which is a distinctive feature of the navvy, enables the jib to be swung round further, and renders the ground in front much more accessible when laying down the rails.

At each corner of the frame is a strong jack-screw S, and a fifth is placed immediately under the pivot of the crane post; these take the entire weight when at work. The outside wheels on which the machine is mounted are double-flanged and 10½ feet gauge; and for transport from one cutting to another ordinary single-flanged wheels are also furnished inside, to the standard 4 ft. 8½ ins. gauge.

The tower T may be described as an oblique truncated pyramid, well extended at the base for bolting to the longitudinals of the main frame. It is formed of two plate-sides, stiffened with T irons, and braced together with crossplates and stays; between them is an opening large enough for the driver to watch the motion of the bucket, even when the jib is straight ahead. The top of the pyramid is finished with a roof-plate extended forwards in front for taking the top pivot of the jib, and stiffened by a V shaped girder like that for the bottom pivot; on this table are placed also the guide pulleys for the main chain, Plate 38.

The jib J is stiffened laterally by riveting to its lower member on each side a broad plate placed on edge so as to form an L section, the two sides of the angle being united with knees and gussets. This enables it securely to withstand the heavy twisting strains when cutting in any such material as tough clay mixed with

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boulders. Round the platform M at the base of the post are led the chains connected with the swinging gear.

The engine E is of the ordinary vertical type, with a cross-tube boiler carrying usually 80 lbs. pressure, and a pair of cylinders of 10 HP. nominal; it runs up to 160 or 170 revolutions per minute under the control of a governor. On the crank-shaft is keyed a pinion, gearing into a spur wheel four times its size on the main-drum shaft, from which all the other motions are transmitted.

The main drum D, Plate 38, is tapered, so as to give the engine the most power when the chain is pulling at least advantage, and *vice versâ;* it is loose on the shaft, and is driven by a clutch, and controlled by a powerful footbrake. By a pair of equal spur-wheels motion is given to a second shaft G, on which is mounted a small drum having its own clutch and brake, and winding a light chain for pulling the bucket back; this however is very seldom required, except when the machine is used for dredging.

On the other end of the second shaft G is a double-cone friction-clutch with a pair of reverse bevel-wheels, for driving in either direction a short longitudinal shaft, which at its front end drives a third cross-shaft giving motion to the swinging and propelling gears through a double-ended clutch. A drum H on the shaft winds the swinging chain that is led round the circular platform M on the foot of the crane post; and this drum also has a brake under command of the driver. A pitch-chain K from a pinion upon the shaft drives a wheel keyed on the axle of the front travelling wheels. By means therefore of the bevel wheels and friction cones the driver can move the navvy backwards or forwards, or swing the jib in either direction; and all the different movements can be effected without reversing or stopping the engine, so that no time is lost. A strong cast-iron framework, firmly bolted to the main frame, carries the various shafts.

The bucket arm A, Plate 37, is made of two oak planks, bolted together at top and bottom so as to leave a long slot between them, through which passes the main chain. On the back edge of each plank is a rack, gearing with a pinion fixed on the fulcrum shaft I

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on the top of the jib. The same shaft also carries a swing frame provided with four rollers, which press on iron bars or runners fixed along the front edge of the arm, so as to hold it up close to the fulcrum, while yet allowing it to be moved longitudinally by the racks and pinions for lengthening or shortening it; the movement is given by a pitch-chain wheel on the outer end of the fulcrum shaft I, driven from a pinion on the hand-wheel shaft W, which as already explained is under the control of the wheelman.

The main lifting chain passes from the winding drum D, through the tower T and over the pulleys on the top, through the bucket arm A, over a sheave on the end of the jib J, round a snatch block on the handle of the bucket B, up to another sheave on the jib, and down again to the snatch block, obtaining therefore a treble purchase.

The bucket is shown in detail to a larger scale in Figs. 3 and 4, Plate 39. Its mouth is semi-elliptical, Fig. 3; its cutting edge is of steel, and is protected by four strong picks or teeth N, Fig. 4, which are made so as to be easily renewed when worn, being fixed to the lip of the bucket by countersunk bolts and nuts, as shown in Fig. 5. These picks or teeth are of different strengths according to the stuff to be excavated; in Fig. 4 is shown the arrangement for ordinary material; the chisel-shaped head of one of the stronger kind is shown to a larger scale in Fig. 5, and is suitable for the hardest boulder clay. On the top of the bucket are fixed two plates strongly gusseted, between which the lower end of the arm A is secured by a through pin. There are also four shackles Q furnished with screw swivels, which distribute the strain, and permit the adjustment of the angle that the cutting edge of the bucket makes with the arm. The two top plates also carry the L shaped hinges riveted to the flap or door. The handle or "bale" U of the bucket swings on pins fixed about centrally on each side; it is well arched to allow room for the dirt, and is secured to the snatch block by a pin and strap. The door is fastened by a stout bolt L, fixed on the outside opposite to the hinges, and kept closed by a spiral spring protected by a casing. On the bolt is a short arm passing through a slot in the casing, and connected by a link to the catch lever for opening the door; at the outer end of this lever is a pulley, round

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which a cord C is rove, the free end passing through a sheave on the bucket arm A and thence to the wheelman. By pulling the cord the bolt is withdrawn out of its socket, and the door falls open by its own weight, and hangs vertically; when the bucket falls back from position B to Z, Fig. 1, it overtakes the door, and the bolt and socket being both made with sloping edges, the door latches itself automatically in closing.

Plan of Excavation.—When making a cutting, the navvy first drives a "gullet," unless the excavation be commenced along the side of a bank or hill, as shown in Plates 40 and 41. The output depends mainly upon the completeness of the means for removing the excavated stuff.

The most effective way is to provide double roads, one on either side, branching out by proper curves from a central road, and also connected with the latter by short "jump" lines at abrupt angles immediately behind the navvy, as shown in Fig. 6, Plate 40. On the central road are kept the empty wagons, and on each side is a man with a horse, by whom an empty wagon is brought forwards along the jump to the side of the machine; and as soon as it is filled it is run back along the branch, and another empty is brought up. Meanwhile the wagon on the other side is being filled; and whilst this in its turn is being exchanged for an empty, a second wagon is being filled on the first side. As the work thus proceeds on either side alternately, not a moment need be lost in waiting for wagons; and the jib has the minimum distance to swing round, the dirt from each half of its sweep being delivered on its own side. When say a dozen wagons have accumulated on each of the side roads, the shunting engine makes up a train, and takes them away to be tipped. The central siding behind the machine should be long enough for say thirty wagons at least; and other sidings are of course necessary if the "lead" to the tips be a long distance.

The gullet thus made, Fig. 7, may be 20 or even 30 feet deep, according to the nature of the stuff; but 25 feet is about the most economical depth, because the machine has then sufficient reach to make the cutting exactly large enough for an ordinary double-line

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railway of standard gauge, the slopes requiring very little hand-work to finish them, as shown by the section in Fig. 10, Plate 41. In Fig. 11 is shown a cutting 50 feet deep for a similar railway, which can be best made by driving two navvies, one in advance of the other, to take out the first 25 feet; and then finishing the lower half of the depth with a gullet similar to that shown in Fig. 10. In each case the completed cutting is shown by the dark section, and the part to be taken out by hand by a lighter shade. In the deep cutting, Fig. 11, the sleepers and ballast of the permanent way are drawn in; whilst in the other, Fig. 10, are shown the positions of the side roads while the work is in progress.

Where the railway has only a single line, as in Fig. 12, Plate 41, the cutting must be made narrower; the navvy is then placed out of centre, and one side-road only can be used. More attention is therefore required for keeping up the supply of empty wagons; and the jib having to swing round through a greater average distance, the output is not quite so good. In Fig. 12 is represented a cutting 25 feet deep for a single line.

For a wide canal, Fig. 13, Plate 41, three or more machines slightly in advance of one another may be used, the centre one leading. A similar arrangement was employed in making the new channel of the river Witham, near Boston.

After a gullet has been driven, the excavation may however be widened in another way, often employed in dock and harbour works, namely by working along a "side face" with a single road, as in Figs. 8 and 9, Plate 40. A train of empty wagons can then be drawn up alongside the navvy; and each truck as it is filled is pulled backwards by the locomotive, so as to bring the next one into the right place for receiving the contents of the bucket, no horse being then required. But although this appears a very simple plan, it is found difficult in practice to move each wagon through just the right distance; and time is lost, and the dirt spilt about. It is therefore best to store the empties behind the machine as before, and bring each forward over a jump to be loaded; in this way, with experienced men on the machine, two horses can be kept going. The jump lines should of course be as near to the machine

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as possible, and the central road should follow up close with the coal truck and the water-tank wagon. Two or more navvies also can be worked along the same face ahead of each other, the centre road forming the side road for the one behind, and so on; as in the section Fig. 14, Plate 41.

The size of the excavation, the material, the facilities for tipping &c., will in each case determine which system can be used with the greatest advantage. With the hardest and most tenacious clay, about 22 feet is the best depth, as then no wedging down is required of the stuff above the reach of the bucket teeth. With loose earth 30 feet can be just as easily taken, since it all falls down to the machine. Within these limits, the deeper the face the better, as the greatest quantity can then be scooped out between each forward movement. To stop, ease the jack-screws, lay rails, run the navvy forwards, tighten down the screws, and get to work again, requires from five to ten minutes, during which of course no wagons are filled. The fewer the stops in the day, the greater will be the number of wagons filled; and the larger the quantity of material within reach of the bucket, the less seldom need the navvy be moved forwards. A good deep gullet offers as a rule the most advantage, because the whole of the semicircle in front of the machine can be cut round, and not merely part as in the side-face cutting; there is better facility for changing the wagons smartly, and there is a shorter average distance for the jib to swing through in order to get over the wagon. All these things economise time and increase the duty, for a few minutes' loss now and then means fewer cubic yards got out in the day.

Men employed.—How small this loss is permitted to be depends even more upon good management than upon the system employed; and of equal importance is the skill of the driver and wheelman on the machine. From the nature of their duties it will be apparent that they must work well together; and good sense and smartness are necessary for obtaining the best results. When handy and suitable men are chosen, their training is soon accomplished; indeed by the time the excavating is in full working order, it will generally

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be found that the necessary dexterity has been acquired. The driver takes the lead, and is usually paid so much extra for each wagon filled per day beyond a stipulated number. If he fills 230 wagons, for instance, he receives his day's pay; but if 280 wagons, 1¼ day's pay; it is thus to his interest to take care no time is lost. Besides these two, there is a fireman to stoke and clean.

The rest of the help depends upon the cutting. As a rule there may be added one ganger and eight men, to act as plate-layers and lay the roads for the wagons and navvy, and to trim the slopes; one man on the top to break down the loose earth, and either one or two horses with their drivers: or say a total of fifteen men and two horses. Where the excavation is extra deep and of very hard material, another man may be required on the bank above, and perhaps extra help on the slopes. With these exceptions the labour remains fairly the same, whatever be the kind of stuff. For dock work, where the slopes do not require finishing till the side is reached, the labour will be proportionately somewhat less than in a railway cutting, and nine to twelve men may be taken as the average. When blasting is necessary, extra help has of course to be reckoned for.

Output.—The output is affected by the hardness of the stuff. For the very hardest clay intermixed with stones and boulders, the capacity of the bucket is 1 cubic yard; for all other hard stuff 1¼ yard, which is the most useful size; whilst for loose earth, sand, gravel, or drift, 1½ or even 1¾ yard can be used.

For all sizes of bucket the number of cuts per hour remains approximately the same, about three-quarters of a minute being the time necessary for each. Moving forwards, laying rails, and waiting for wagons, may be set down as a deduction of 10 minutes per hour, leaving 50 minutes for cutting, which gives say 60 as the number of bucket loads per hour, or 600 per day of ten hours, as the theoretical capacity, equivalent to a daily output of 600, 750, and 900 cubic yards with the 1-yard, 1¼-yard, and 1½-yard buckets respectively; and this agrees well with the results actually obtained.

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Working Expenses.—The working expenses vary according to the locality. The following examples, taken from two different contracts, in the south of England and in Scotland respectively, may be considered as representing the two extremes, the output being in each case about equal.

South of England.				*Scotland.*			
One engine-driver . . .		7	6	One engine-driver . . .		5	0
One wheelman		4	6	One wheelman		4	0
One fireman		3	6	One fireman		2	6
One ganger		8	4	One ganger		4	6
Eight men at 4*s.* 6*d.* . .	1	16	0	Eight men at 3*s.*	1	4	0
Two horses and two drivers	1	0	0	One horse and driver . .		10	0
One man at top		4	6	One man at top		3	0
10 cwts. of coal at 36*s.* . .		18	0	10 cwts. of coal at 6*s.* . .		3	0
Water, oil, and waste . .		2	6	500 gals. of water . . .			3
				Oil, tallow, and waste . .		2	6
Total per day . .	£5	4	10	Total per day . .	£2	18	9

In the first example the prices are all high, particularly that of the coal. In the second the prices are moderately low. The average may therefore be set down at from £3 10*s.* to £4 per day.

For depreciation, repairs, and interest on capital, about £1 per day may be reckoned, being arrived at as follows. The total cost of the machine weighing 32 tons is about £1250: namely £1175 price at the works, and £75 for carriage and erection on the site of the excavation; but in many cases the amount allowed for erection can be considerably reduced.

Depreciation at 10 per cent. on £1250 . . .	125	0	0
Repairs and renewals at 5 per cent. . . .	62	10	0
Interest on outlay at 5 per cent.	62	10	0
Total per year . .	£250	0	0

This amount may be considered to be well over the mark. Allowing therefore 300 working days in the year, and deducting two days per month for stoppages through bad weather, about 270 available days will remain. The amount to be reckoned under

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the above items will therefore be 18*s.* 6*d.* per day, or about one-third of a penny per cubic yard, or say from three farthings to one penny per wagon.

Making all allowances therefore, the total cost of the machine may be set down at say £4 15*s.* per day; which, divided by the output, gives as the cost of excavation say three halfpence per cubic yard for sand or gravel, and twopence for hard clay. Where the excavation is small, or the machine is under a disadvantage, these prices will of course be somewhat exceeded; and twopence to threepence per cubic yard may then be allowed. The following results, obtained directly from contractors using the navvy, show a substantial agreement in this respect.

Kind of cutting.	*Material.*	*Size of bucket. Cubic yard.*	*Cubic yards per day.*	*Cost per cubic yard. Pence.*
1. Dock works.	Boulder clay.	1	480	1½
2. Railway cuttings.	Chalk with stratum of flints.	1¼	500	2½
3. Harbour works.	Clay.	1	660	3
4. Dock works.	Hard red marl.	1½	940	2
5. Dock works.	Hard red marl.	1½	740	2½

It is difficult to estimate the cost of doing the same amount of work by hand, but a saving of 2*d.* to 6*d.* per cubic yard may be safely reckoned upon. Where the stuff is hard it is still greater. For stiff brown clay 10¾*d.* per yard has been given as the cost; and for stiff hard tough clay, containing boulders weighing from ½ cwt. to 4 tons, the cost was estimated at 1*s.* 6*d.* per cubic yard by hand labour, whilst the cost was 4¾*d.* by the machine, which was one of the earliest sent out. With the present stronger machines the cost would have been still less; in short the harder the stuff, the greater is the economy over hand work.

Equivalent Hand Labour.—The number of men required to do the work by hand will vary very much. For instance, in excavating 190 cubic yards per day the following men were necessary:—one ganger, ten gullet men, seventeen wingmen, two platelayers, one brakesman, two horses and two drivers; or a total of thirty-three men and two horses. At the same rate to excavate by hand 600

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yards per day, as the navvy does, one hundred men would be required. The steam navvy may therefore be considered equal to at least seventy or eighty men.

The machine gives also the important advantages of enabling faster progress to be made, and economising time, as none is lost in disputes with the men; the cost of excavation can therefore be estimated with greater accuracy, and when once it has been determined for a given cutting, the rate may be relied upon till its completion. The contractor therefore is practically independent of strikes in this department of his business; and is further relieved of the trouble of getting together so large a body of men, and of housing and providing for them in out-of-the-way districts.

Subaqueous Work.—The navvy can also be worked for excavations under water, for which purpose it is mounted on a pontoon, as shown in Fig. 15, Plate 42. The pontoon is about 50 ft. long by 22 ft. wide, and draws 2½ ft. of water; it is built specially to receive the machine, and is most conveniently made of iron; but where timber is on the spot and plentiful, it may be of course substituted with advantage. For better distributing the weight in the pontoon, the frame of the navvy is divided transversely, and a distance piece is bolted in between for completing the continuity. Extra stays are carried back from the top of the tower down to the engine end; and an extra roller R is put in, to take the sag out of the main chain. Rollers are also provided under the step of the jib for the drawing-back chain that winds upon the drum on the second shaft. The bucket arm has of course to be lengthened, according to the depth to be taken out; and the bucket is made with rather more taper, for the stuff to clear itself, and is pierced with holes to let out the water. The action is similar to that on land, except that the resistance of the water somewhat impedes the back swing of the bucket, necessitating the use of the drawback chain. The pontoon is steadied by three piles or legs, one at each front corner on either side of the jib, and one centrally behind the engine; these are provided with racks and pauls, and are raised by hand levers; two or three crabs, with guy ropes attached to anchors or otherwise, are

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also necessary. The machine delivers into a barge moored on one side of the pontoon, a second empty barge being brought up on the other side ready to receive the stuff as soon as the first is full. When all within reach of the bucket has been excavated to the required depth, the piles are raised, and the pontoon hauled forwards by the guy ropes; the piles are then dropped again, and the next piece in front is excavated.

The deeper the face, the better; indeed a very shallow face can hardly be dealt with successfully. The water also should be comparatively still, as waves lift the pontoon and interfere with the bucket taking its proper cut; the output can be averaged at about half what it would be on land. The cost per cubic yard may be taken at about double that of a dry excavation with similar depth of face, up to say 6 feet; but it will also vary according to the depth below the water line.

As a dredger the machine has not been extensively tried. For mud and sand it is hardly considered as a competitor of the dredgers in ordinary use; but where there is a very hard bottom and a fair face to work at, it offers without doubt very considerable advantages.

Discussion.

Mr. Ruston mentioned that on the occasion of the visit of the members to his works that afternoon one of the machines would be exhibited in full operation, except that it would not be actually excavating, but every movement would be performed in exactly the same way as in the actual work of excavation. The machine itself was one which so far had been a practical success, and indeed had exceeded any expectations which he had at first formed of it. However happy any idea might be, it was one thing to conceive it and another thing to bring it into successful operation. That was more particularly the case where machinery was subjected to the

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(Mr. Ruston.)
rough usage which it often met with in railway contracts and works of that kind, than it was in a well kept engine-house or factory such as many of those which mechanical engineers were accustomed themselves to control. The idea of the steam navvy however had been followed out from its origin, until the machine had become a perfect success. The parts which had at first been found to be weak had been strengthened, and the parts which required special adaptation had been carefully considered; and he believed that every one who saw it at work would be under the impression that it was very little else than a mechanical toy, owing to the remarkable ease and simplicity of its actual working.

Mr. EDWARD B. MARTEN had often seen the machines at work, but generally upon a homogeneous material. He should be glad therefore to know how they would act if they suddenly came upon a boulder. That appeared to him to be the greatest difficulty likely to occur. When cutting in a rather soft soil, and coming suddenly on a very hard and rough rock, what would the machine do?

Mr. JOSEPH ADAMSON had seen the machine at work at Coble Dene dock, Tynemouth, and when it came to a boulder it simply tore it out and turned it into the wagon, which he supposed was what it was intended to do. He had also watched the machine at work in the Northumberland dock at Newcastle, where it was certainly working, as the author had said, like a mechanical toy in respect of ease and simplicity.

Mr. ROBERT S. BOYER said, although he had had no personal experience in connection with this machine, he had seen it at work at Penarth in stiff clay, and it certainly worked exceedingly well. When it came to a boulder, it went on with the cut without any difficulty, and fetched it out: unless of course the boulder was too large, when it would bring the machine up.

Mr. T. HURRY RICHES said at the Cardiff meeting last summer many of the members had no doubt seen these machines at work at

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Penarth and at the new docks, where they were excavating in marl and blue lias. The mode of working there was to use light charges of dynamite to shake the rock, and then the navvy tore it out. The machine worked satisfactorily in every instance. He had seen it pulled up by taking too deep a cut and so getting too much to do; but that was the fault of the man in keeping it too close to its work. In his own experience the work had been done in a very satisfactory manner. The only material he had seen the machine working in was blue lias, red marl, and blue clay.

Mr. R. Price-Williams could not but express his great admiration of such a labour-saving machine as that just described; for he remembered how, when the Lancaster and Carlisle line was being constructed many years ago, the price for excavating loose stuff was fourteen pence per yard; and in recent estimates which he had prepared for a railway near London the price for excavating the London clay was also fourteen pence per yard. Contrasting that with the prices mentioned in the paper, the important economy of the steam navvy would at once be realised. He could only regret that the machine had not been available for the deep clay cuttings through which London was approached by the North Western and indeed by all the principal railways having their termini in London. Had such an economiser of labour been in use at the time those cuttings were excavated, a very large sum would have been saved. In this country the greater part of the railway system was now completed; but there was still a great future he believed for the steam navvy in the construction of railways yet to be made, particularly near London, the London clay being a material for which the machine was especially suitable. It would also be useful in excavating docks and canals. It was easy to see that the economy to be obtained by its employment in the construction of a large work like the Manchester Ship Canal would be very great indeed.

Mr. Benjamin Walker said that from the description given in the paper he should be led from a mechanical point of view to expect great success for the steam navvy. Though not having had

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(Mr. Benjamin Walker.)

the good fortune to see the machine at work, the evidence of those who had seen it was a sufficient guarantee of its excellence. Lincoln he trusted would become as famous for the manufacture of steam navvies as it had already become for that of portable engines. The mechanical engineers of the country could not have come to a place where more good work had been done in the manufacture of portable engines than had been done at Lincoln. Certainly the original manufacture started by Mr. Clayton and his partner, the late Mr. Shuttleworth, had done immense service in this district. That firm had been the first to begin the work which had been so successfully carried out. He well remembered being told by them some thirty-three years ago that they intended to make the best and cheapest portable engine, and that they intended to make it so well and so cheap that it should be sure to be bought in large numbers. They considered that to be a sufficient problem for them to solve—to do the work well and cheap. Such an aim could not be too much kept in mind in the present days of bad trade. Mechanical engineers in this country, having to compete with all the world, would do well to follow the example of Messrs. Clayton and Shuttleworth by taking up a certain section of work and doing it so well and at so low a price that no one could compete with them; and then they would be sure to get work. They had now also the further example afforded by Mr. Ruston, who had certainly worked out the steam navvy with an ability which no one could question.

Mr. Joseph Tomlinson had seen the navvy at work, and it certainly did work admirably. Nothing seemed to stop it, except, as Mr. Riches had said, when it was pulled up by giving it too much to do. It did everything that the author said it did, and was managed with such ease that it might truly be called a mechanical toy of very huge dimensions; and it did a huge amount of work.

Mr. Sydney F. Walker had seen these navvies at different places, and had been much struck with the beautiful way in which they did their work. It had occurred to him that the cost and weight might be reduced, if the machine were worked by electro-motors by means

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of wires. In most large contracts it was necessary to have large fitting shops, requiring large boilers and engines; and it would be a simple matter to drive a generator, and from it to carry wires of a comparatively small size to where the navvy had to be employed. That plan would get rid of the weight of the boiler on the navvy, a large portion of the weight of the engine, and the weight of the water tank; and there would not be the trouble of supplying the navvy with coal and water. It was true that the weight of the boiler and engine and water-tank acted as a counter-balance; but he presumed these could be replaced by other dead weights, if it could be shown to be an advantage to work the machine by electricity; and such a plan would get rid of the fireman's wages and other similar expenses.

Sir James N. Douglass had had the opportunity of witnessing the machine in operation at the Coble Dene dock, where he knew it had given great satisfaction to the engineer, Mr. Messent. He had been particularly struck with the excellent and complete way in which it did its work; its automatic performance was simply perfect. A good horse wanted a good rider; and this machine, however perfect and complete in itself, certainly required a good driver. On some occasions he had noticed that the bucket had been overloaded and overstrained, as had been referred to, and there was a slight halt; but there never appeared to be a complete stoppage. On other occasions the bucket was not quite filled; but that was only due to the imperfection of the driver's management at the time. He could easily understand that an expert driver could work the machine so well as to fill the bucket completely; and not only fill it completely, but, which was another very important matter, completely tip it into the wagon without any spilling. The way in which the stuff was put into the wagon he considered a most complete operation.

Mr. Ruston in reply said that, in carrying out this machine from its earliest inception, the great object he had kept in view had been to adapt it to every kind of material which such a machine might be expected to have to excavate. The first difficult material that it had had to deal with had been encountered a short time after

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(Mr. Ruston.)

the original construction of the machine, and was on the line of the Midland Railway passing by Melton to Nottingham. There the material was found to be a homogeneous clay, but exceedingly hard; and it was being excavated during a dry baking summer which rendered the clay so hard that the men working by hand could not get their pickaxes more than an inch or an inch and a half into it. At that time the jib carrying the bucket was found to be too light, and in one or two of the navvies it was crumpled up, simply because the engine had more power than the other parts of the machine; but when those parts were strengthened, and the bucket was driven properly, it cut the homogeneous clay which defied the pickaxe, and dug it out as cheese was cut with a cheese knife.

Another machine, sent to work somewhere between Hartlepool and Darlington for the North Eastern Railway, met with a sort of conglomerate, in which certain stones were imbedded as if set with Roman cement. There for the first time the heavy steel picks on the bucket were adopted (Fig. 5, Plate 39). These of course were not needed for clay, which, however hard, was a homogeneous material; but by their adoption the difficulty with the conglomerate was perfectly overcome, all the parts of the machine being made of the necessary strength. Afterwards some of the navvies were sent to Greenock, where new docks were being made; and there they excavated the boulder clay, in which occurred stones of a very much larger size. The opportune question asked by Mr. Marten related to one of the crucial points in the problem that had to be solved. When a boulder or block of stone was found, too large for the bucket to grasp and deal with, the wheelman by easing his footbrake allowed the bucket to fall back from the cut it was taking and to clear itself from the face of the bank. In this way a boulder or a reef of rock which the bucket could not cut through could be undercut by degrees, until it overhung far enough to be broken down or to break down of itself. In that way all difficulty was overcome, and all risk of injury to the machine was avoided. The one great thing that was essential in all cases was to make the engine the weakest part of the machine, so that when the cutting became too severe for it the engine should be pulled up without any harm being done.

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With respect to electro-motors, if it should be found that electrical power could be applied to work the navvy much more economically and efficiently than steam, then he imagined it would be applied; but for practical purposes he had always found steam sufficient. The weight of the engine and boiler and water-tank, as had been remarked, was wanted for the stability of the machine in working; but of course that stability could be obtained by loading with pig-iron just as well as with a costly engine.

At Boston, where a new outfall for the river Witham had been made, exceeding in section the Suez canal, three navvies worked abreast, excavating the cutting at a very rapid rate.

With regard to the remark made by Sir James Douglass, it was precisely the fact that the speed and efficiency of the machine depended altogether upon the skill of the two men who were working it. The driver standing beside the engine, who put the clutches in and out of gear, was generally a skilled mechanic; the wheelman, acting under the driver's orders and in concert with him, was generally a contractor's labourer who in a fortnight became practically competent for everything he ought to do in working the machine.

The President said the steam navvy appeared to him to be a machine having characteristics of a special kind. There was not much difficulty in performing the usual operations of mechanical engineering, if only a fixed and substantial base or fulcrum was available to work from. But here was a case where very great force was exerted, and yet where there was only a shifting or movable base to work from. That was one of the chief peculiarities in the present instance, and he thought the difficulty had been surmounted with remarkable ability. A somewhat analogous case was that of steam ploughing, where the plough offered at times great resistance, and the fulcrum was an engine which also moved along the headland. But the resistance in the case of the navvy was much greater than in the case of steam ploughing; perhaps steam draining came nearer to it. As in the case of steam ploughing or steam draining, the greater the resistance offered by the soil, the greater was the advantage of steam machinery over human or animal labour. In fact in steam

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(The President.)

ploughing and steam draining, when a certain depth or a certain toughness of soil was exceeded, the work was such that it could not be done by animal power at all. This seemed to be the case also with the navvy. The machine was able not only to do work cheaper than by hand, in proportion to the difficulties surmounted, but also to do work that could not be done at all by unaided labour.

The interesting paper just read was one of which any Institution might be proud; and he asked the members to join in according a very hearty vote of thanks to the author for it.

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SEMI-PORTABLE ENGINE.

Plate 43.

20 H.P. *Semi-portable Winding and Pumping Engine.*

Fig. 1. *End Elevation.*

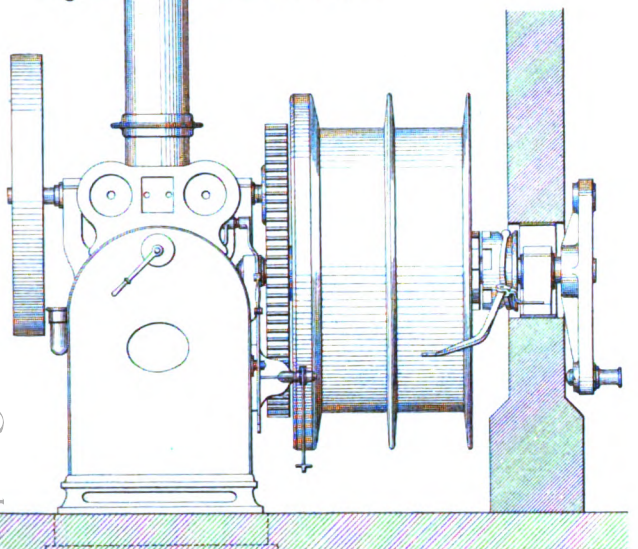
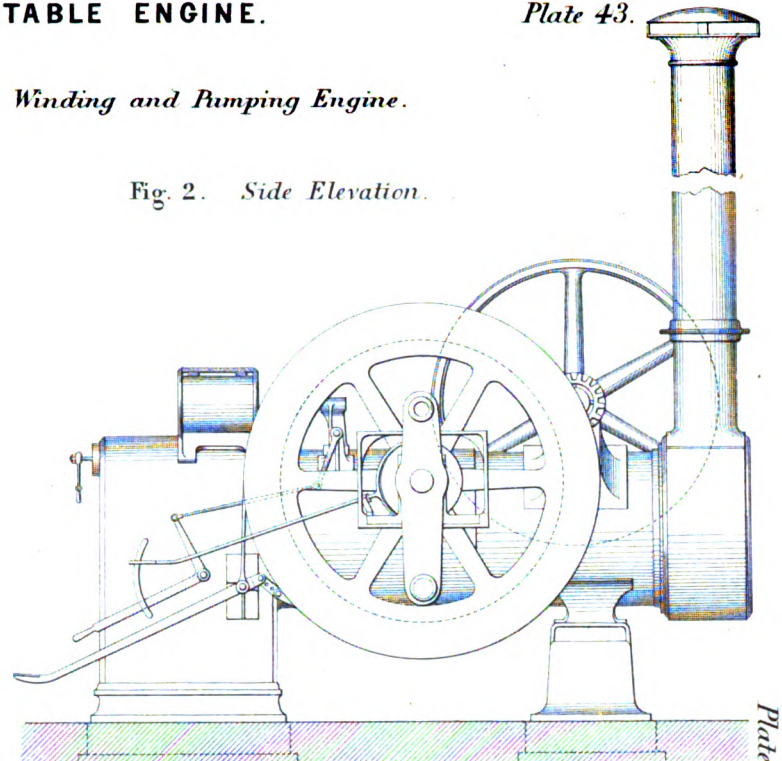


Fig. 2. *Side Elevation.*



(Proceedings Inst. M.E. 1885.)

Scale 1/50th

0 5 10 15 Feet.

Plate 43.

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SEMI-PORTABLE ENGINE.

Improved 20 H.P. *Semi-portable Winding Engine.*

Fig. 3. *Side Elevation.*

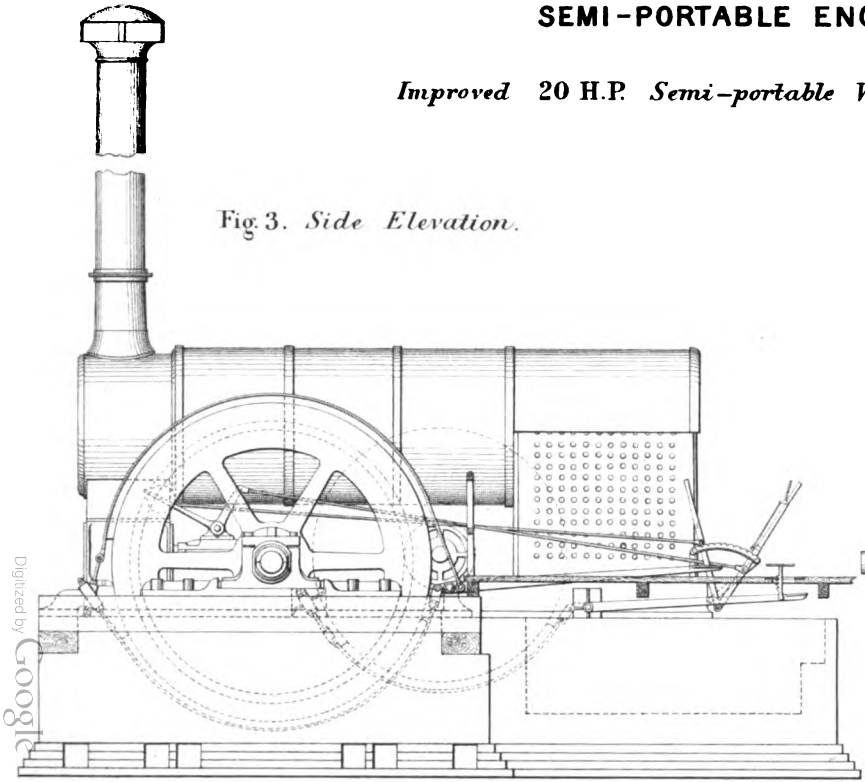
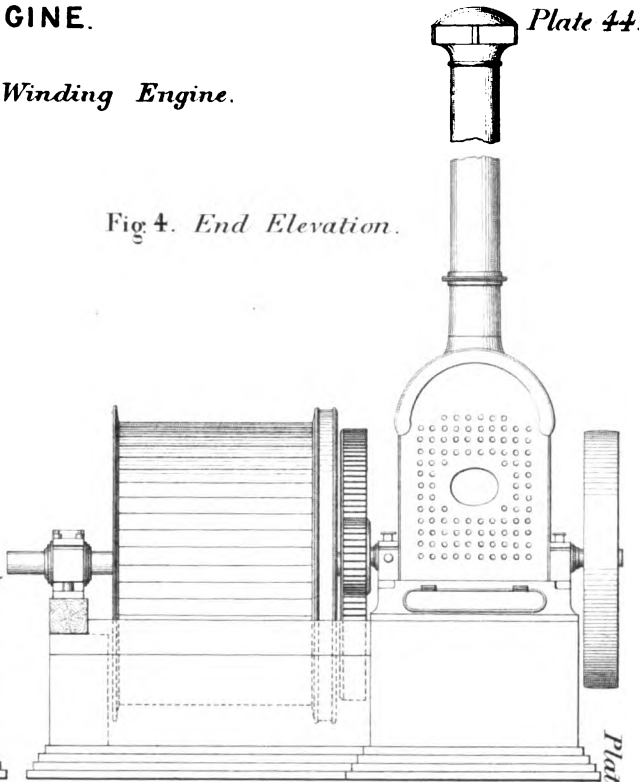


Fig. 4. *End Elevation.*



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(Proceedings Inst. M.E. 1885.) *Scale 1/70 th*

0 5 10 15 20 Feet.

Plate 44.

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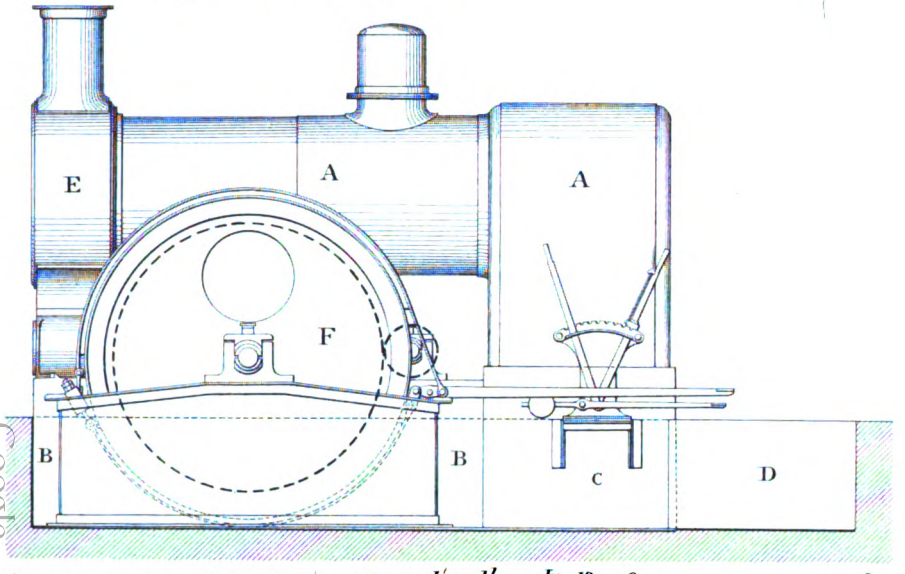
SEMI-PORTABLE ENGINE

Plate 45.

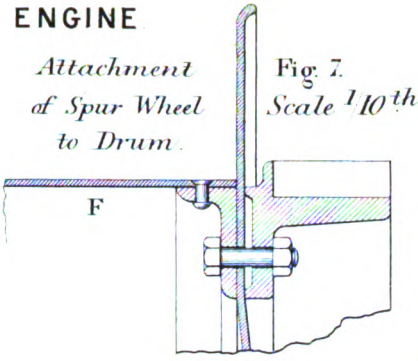
Semi-portable Winding Engine with wrought-iron foundations.

Fig. 5. *Side Elevation.*



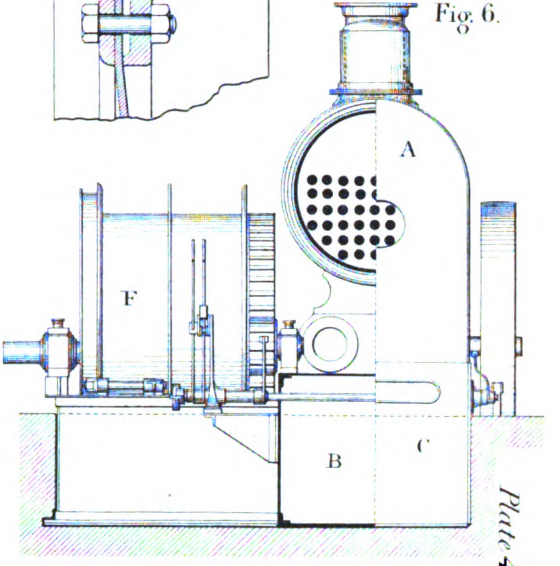
Attachment of Spur Wheel to Drum.

Fig. 7. *Scale 1/10th*



End Elevation.

Fig. 6.



(Proceedings Inst. M.E. 1885.) *Scale 1/50th*

Ins. 12 0 5 10 15 Feet.

Plate 45.

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SEMI-PORTABLE ENGINE.

Plate 46.

Engine packed for transport.

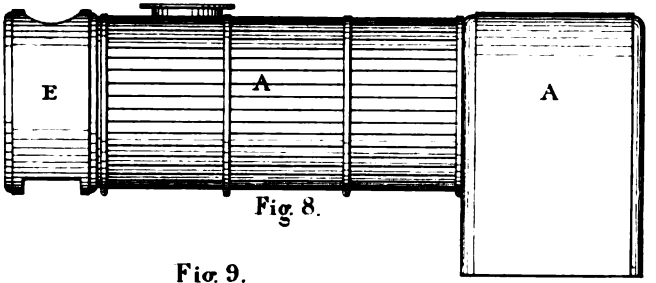

Fig. 8.

Fig. 9.

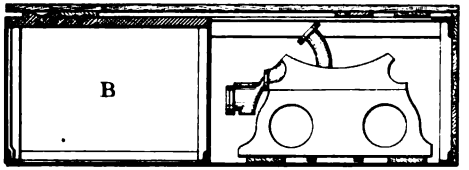

Fig. 10.

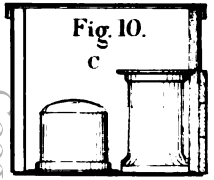

Fig. 11.

(Proceedings Inst M.E. 1885.)

Scale 1/50th

0 5 10 Feet.

40-H.P. *Compound Condensing Engine.*

Fig. 12. *End Elevation. Scale 1/30th*

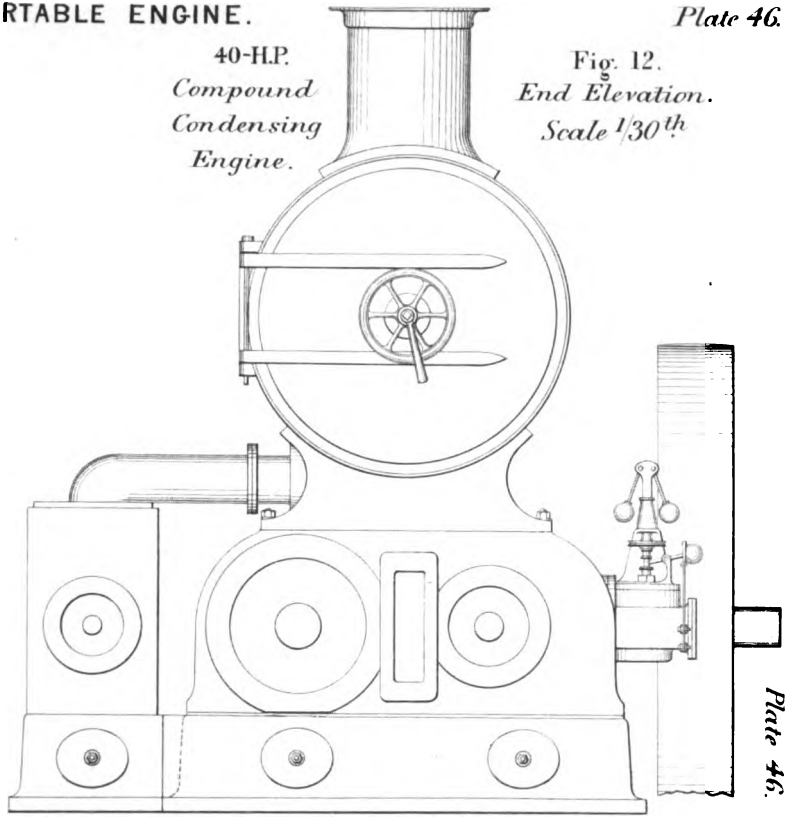

Plate 46.

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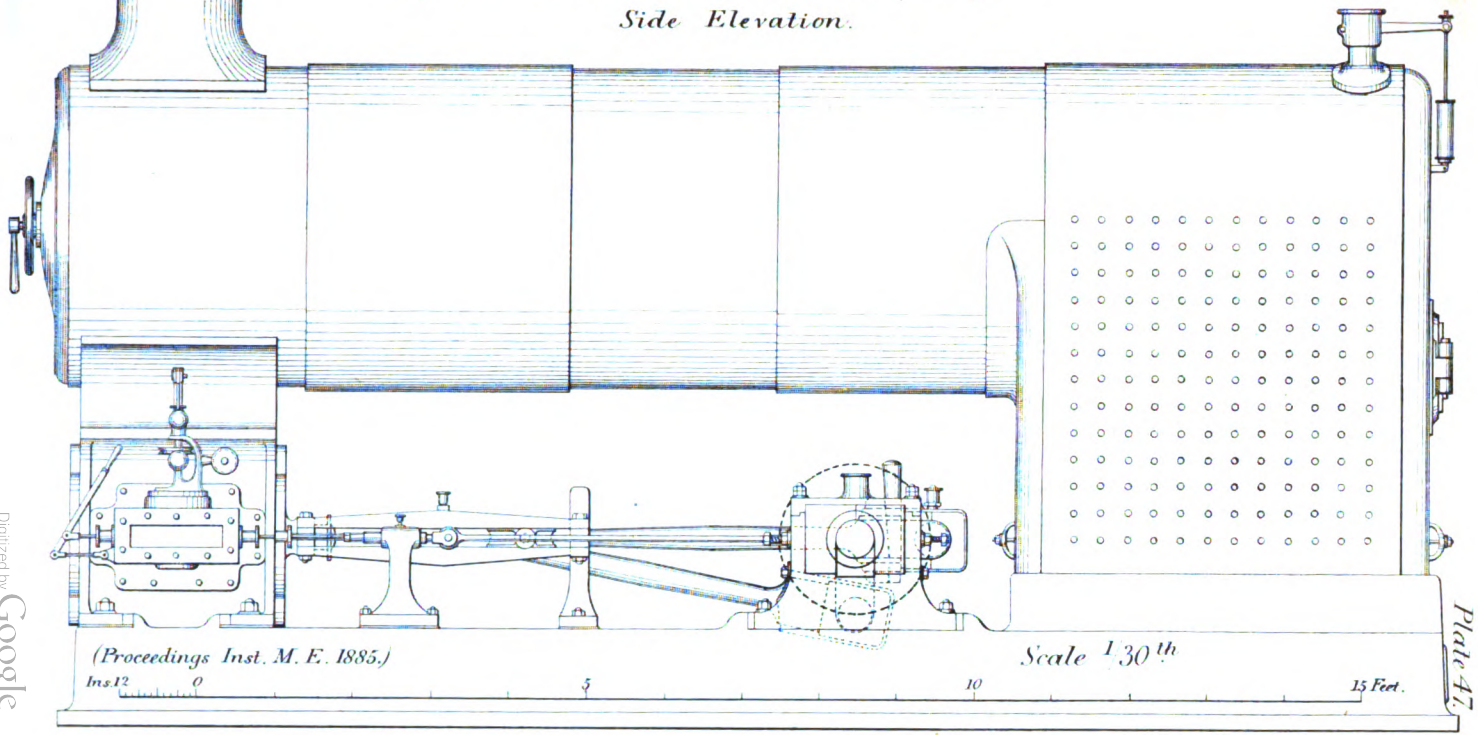
SEMI-PORTABLE ENGINE.

Fig 13. 40-H.P. *Compound Condensing Engine.*

Side Elevation.



(Proceedings Inst. M. E. 1885.)

Scale $\frac{1}{30}$th

Ins. 12 0 5 10 15 Feet.

Plate 47.

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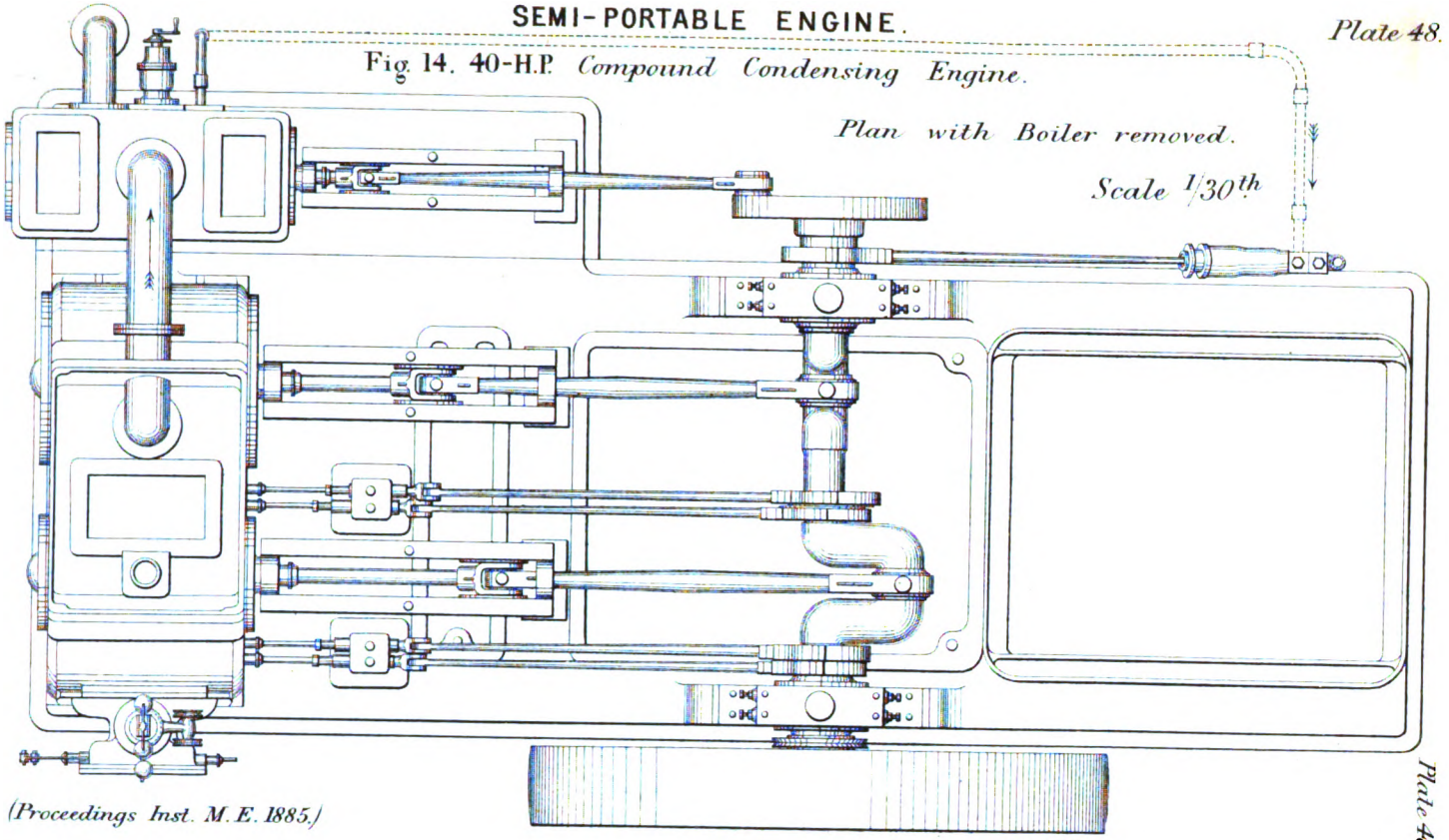
SEMI-PORTABLE ENGINE.

Fig. 14. 40-H.P. *Compound Condensing Engine.*

Plan with Boiler removed.

Scale 1/30th



(Proceedings Inst. M. E. 1885.)

Plate 48.

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Fig. 15.

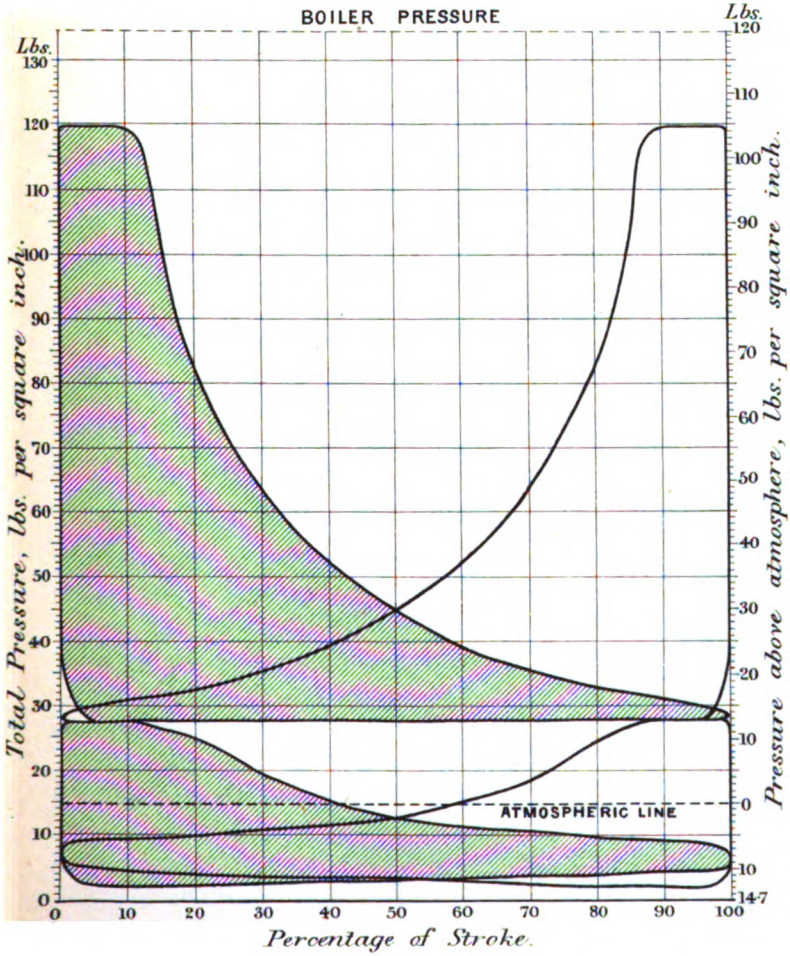
Indicator Diagrams

from Compound Semi-Portable Engine.

High-pressure Cylinder ... 12 *inches diameter.*

Low-pressure Cylinder ... 21 *inches diameter.*

2 *feet stroke.* 90 *revs. per min.* 90 *Horse power.*



(Proceedings Inst. M. E. 1885.)

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ON RECENT ADAPTATIONS OF THE ROBEY SEMI-PORTABLE ENGINE.

By Mr. JOHN RICHARDSON, of Lincoln.

Portable Engine.—On the occasion of the Summer Meeting of the Institution at Penzance in 1873 (Proceedings, page 167) the author had the pleasure of reading a paper on the application of Portable Engines for mining purposes, a number of engines of Messrs. Robey's manufacture being then successfully at work in Cornwall and elsewhere. The subject attracted considerable attention among the Cornish miners and engineers, and the use of such engines for mining work has since then rapidly extended, and their horse-power considerably increased. Up to that time these engines had seldom been made over 25 HP. nominal; but within two years of that date a number of them were in use having a pair of cylinders of 16 inches diameter and 24 inches stroke, developing easily 150 HP., and constructed as represented in Figs. 1 and 2, Plate 43.

Semi-Portable Engine.—It was while engaged in the construction of these large semi-portable engines with their powerful gear that the author conceived the idea of making that radical change in their construction, which resulted in what is now so well known as the Robey Semi-Portable Engine, of which the first designed and made was that represented in Figs. 3 and 4, Plate 44. All the main features of this first engine have since been adhered to, while sundry improvements in detail have been introduced from time to time.

The engine, as will be seen, is erected on a massive cast-iron foundation plate, to which all the working parts are fixed, together with one of the drum-shaft bearings, and the brackets for carrying the brake-straps and levers. The whole of the strains due to the working of the machinery are contained within the base plate, and

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are brought, as they should be, near to the position of greatest stability, namely the ground line: while the boiler is set free from all mechanical strain, and is left to its legitimate purpose of making steam. The great advantage for stationary purposes which is possessed by this semi-portable form of engine in comparison with the portable engine type will at once be seen by comparing engines of the two designs and of the same size and power, as shown in Plates 43 and 44.

Sinking Engine.—One of the first engines made of this size was used for the sinking of the Florence shaft at a colliery belonging to the Duke of Sutherland, near Trentham, Staffordshire. The shaft is 12½ feet diameter, and was sunk by this engine to a depth of 530 yards at an average rate of eight yards per week. After bottoming the pit, the engine was put to draw coal from a depth of 340 yards, drawing on an average 170 tons in every shift of eight hours, or 510 tons per day of twenty-four hours; and it continued to do this work until the erection of the permanent winding engine, when this sinking engine, deprived of its winding gear, was used as a permanent engine to drive the saw-mill machinery and fitting shop.

Since that time some hundreds of similar engines have been put to work in various parts of the world. The great success attending their use, coupled with their many other qualifications, have largely recommended them for export, especially to those foreign countries where skilled labour is scarce. The engine being self-contained requires no fitting; it possesses great strength with small weight and space; it is cheap in transport; it requires little expense in foundation, and can quickly and therefore cheaply be fixed and put to work; and it is so simple in construction and in use that unskilled labour can soon be taught to manage it.

Lighter Engine.—Notwithstanding these advantages however, there are parts of the world difficult of access, where mining engines are needed, and where the requirements are such as to call for still further modifications. For example, when an engine has to be

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transported over several hundred miles of country or desert without the facilities of a railway, every pound in weight saved is of much importance, since instances occur where the cost of transport to its destination exceeds the original cost of the machinery. In such cases if any kind of building material has also to be similarly transported, it becomes a matter of equal importance to dispense altogether with auxiliary foundations.

To meet these conditions the engine shown in Figs. 5 to 7, Plate 45, has been specially designed. Here wrought iron and steel have been substituted for cast iron as far as practicable, with the result of a large saving in dead weight and consequent saving in cost of transport. An engine of 100 HP. actual, with its boiler and winding gear and foundations complete, has a total weight of only 27¼ tons; and one of 65 HP. actual, with its similar accessories, weighs only 16½ tons. The wrought-iron tank foundation is so made that it is readily taken to pieces, being divisible into three parts, B, C, D, Fig. 5. The boiler A is also easily disconnected at the smoke-box E. Thus with the drum F there are six comparatively small packages to deal with, of which the total cubic measurement for shipment is much less than of the machine as a whole.

In Figs. 8 to 11, Plate 46, are shown these separate parts when packed for transport. The three parts B, C, D, Figs. 9 to 11, together with the smoke-box E, Fig. 8, contain within them all the finished parts of the engine, tools, waste, and in fact any other goods, until the dead-weight equals the cubic measurement for shipment. It will be seen that the weight of the packing cases ordinarily used is saved; while the tank foundations used instead, being of strong boiler-plate, effectually preserve the parts from injury throughout a rough journey.

On arrival at their destination, all that is necessary is to level a piece of ground, place case C upon it, unpack and attach the other cases, which can only fit into their proper places; and in a few hours the whole machinery can be put together and set to work. Waste material drawn from the shaft can be piled up around the engine foundation, thus holding the engine more firmly in position as the work proceeds. It is unnecessary to observe that the advantage of

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this arrangement is very considerable where building material and skilled labour can only be had at a great cost.

While this class of engine was originally designed as a mining engine, it is also highly suitable for many other purposes; and since the date of its production several thousands have been used for industrial purposes. Engines with some of the main features common to this had indeed been made previous to its introduction: a few stationary engines had been made with the boiler placed over them as in locomotives. Nevertheless the general introduction of this class of stationary motor as a compact self-contained engine and boiler may be said to date from its production by the author's firm in 1874.

Compound Engine.—One of the latest improvements has been compounding the engine: to which mode of construction it readily ends itself, having a boiler that can be easily made to carry the high pressure necessary to render compounding economical. In Figs. 12 to 14, Plates 46 to 48, is shown an engine of 40 HP. nominal, built for pumping purposes, not only compounded, but also fitted with a condenser. Owing to the position in which this particular engine had to be placed, it was impracticable to put the condenser behind and work the air-pump as usual by a prolongation of the low-pressure piston-rod; hence it was placed at the side. So small is the consumption of steam in an engine of this class, that its boiler of ordinary size was found quite ample to supply steam, with only the natural draught of the chimney.

In Fig. 15, Plate 49, are shown indicator diagrams taken from one of these compound engines, the work done being equal to 90 HP., with a boiler pressure of 120 lbs. expanded twenty-one times down to 12½ lbs. below the atmosphere. The consumption of steam was less than 18 lbs. per HP. per hour, a duty probably never before attained in an engine of the semi-portable type, and rarely exceeded in the best and largest class of marine or stationary engines.

Governing.—In an engine used for pumping, any elaborate form of expansion gear would be out of place. The load is really the

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governor, and the expansion valves are better fixed by hand at the most economical point, and so left, an ordinary governor and throttle-valve being merely provided in order to prevent the engine from running away in case of the water failing or of any other accidental circumstance.

When however the speed has to be maintained with varying loads, the engine is fitted with automatic expansion-gear controlled by the governor. Experiments show that the load can then be varied from 21 HP. to 42 HP., with a difference in speed of only 3 revs. per minute or only 2 per cent. For electric lighting this engine is admirably suited, and has been employed with great success, being fitted with an electric speed-regulator, instead of the ordinary centrifugal governor. As this regulator will be fully described in Mr. Nevile's paper on private installations of electric lighting (page 379), it is unnecessary here to mention it further, excepting to call attention to one of its incidental advantages, particularly in connection with compound engines, in which any wide variation in the duty results in loss. Thus a compound engine may be a very economical motor when developing say 50 HP. at 150 revs. per minute, while it would be exceedingly wasteful if called upon to give out only 5 HP. at the same speed. But if the speed can be reduced in proportion to the load, bringing it down to 15 revs. per minute, the pressure and distribution of steam would remain the same; and each stroke of the engine would be delivered with the same economy as when developing the higher power, with the further good result of saving nine-tenths of the friction. The electric regulator enables this desirable result to be obtained; and one of these engines so fitted will be shown at work during this meeting at the works of the author's firm.

(*For Discussion see page* 389.)

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ON PRIVATE INSTALLATIONS OF ELECTRIC LIGHTING.

BY MR. RALPH H. C. NEVILE, OF WELLINGORE.

Having for many years desired to use the Electric Light for Domestic Lighting, the author could not see his way to doing so while arc lights, and those anything but perfect, were all that were commercially practicable. When however incandescent lights were introduced, he decided to make the experiment as soon as possible. Happening to have a 6 HP. portable engine some ten years old, which he had been using for pumping and for driving a saw, he determined to try this for the purpose, although warned that in all probability difficulties would arise in respect of the governing, as proved to be the case, in consequence of the governor being one of the old-fashioned kind with heavy balls revolving at a slow speed. In the course of last summer he arranged with Messrs. Edmundson of Westminster to carry out the wiring of the house, and in the autumn obtained from them a Siemens SD 9 compound shunt-wound dynamo; and completed the installation sufficiently to judge of the merits of electricity *versus* gas, which had been the previous illuminant.

The total number of lamps in the house is 125, divided over some fifty rooms and offices. A ground-floor plan of the arrangement is shown in Fig. 7, Plate 52. The maximum number of lamps hitherto required at one time for purposes other than those of experiment has been fifty. All the main wires within the house have been laid to admit of the full number being used, and even of an increase to 150 or 200. As shown in Plate 52 the engine and dynamo are stationed in a shed about 180 yards distant from the point A, Fig. 7, where the overhead cables enter the house; in this shed also is the saw table, so that by removing the belt from the dynamo and substituting one

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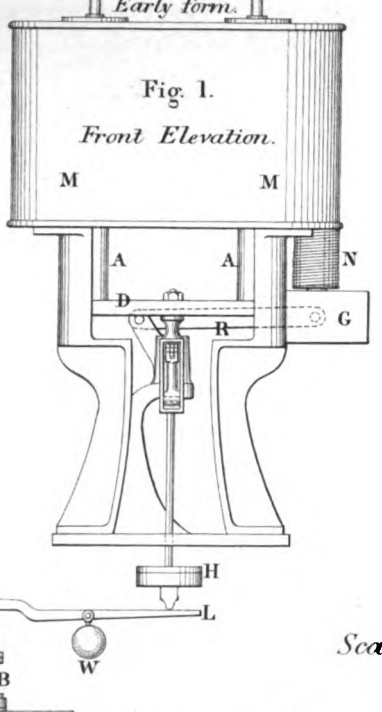
ELECTRIC LIGHTING.

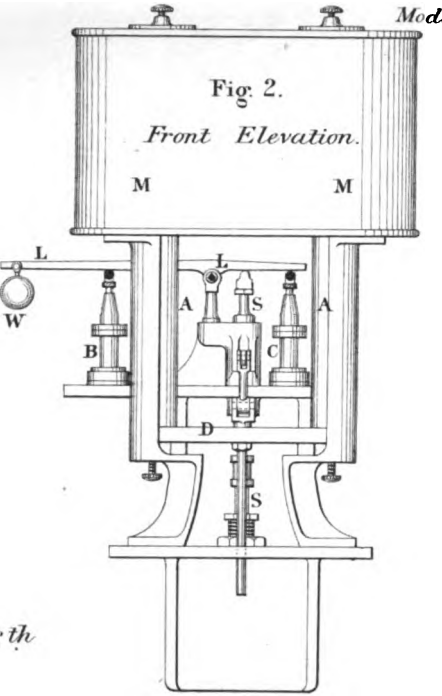
Plate 50.

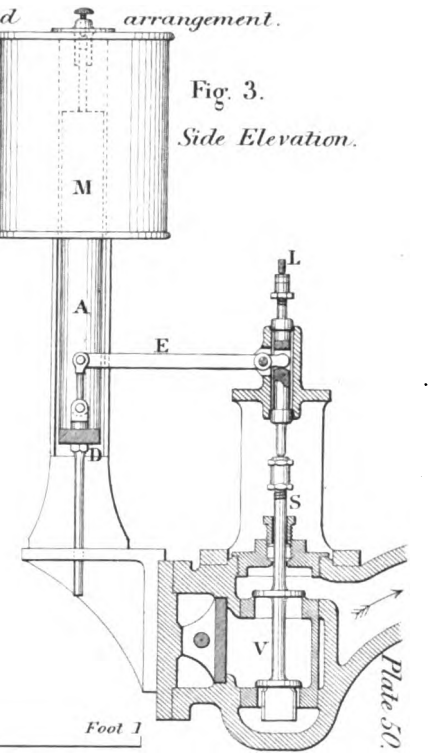
Electrical Governor with Compensating Lever.

Early form.



Modified arrangement.





Scale 1/6th

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(Proceedings Inst. M.E. 1885.)

Plate 50.

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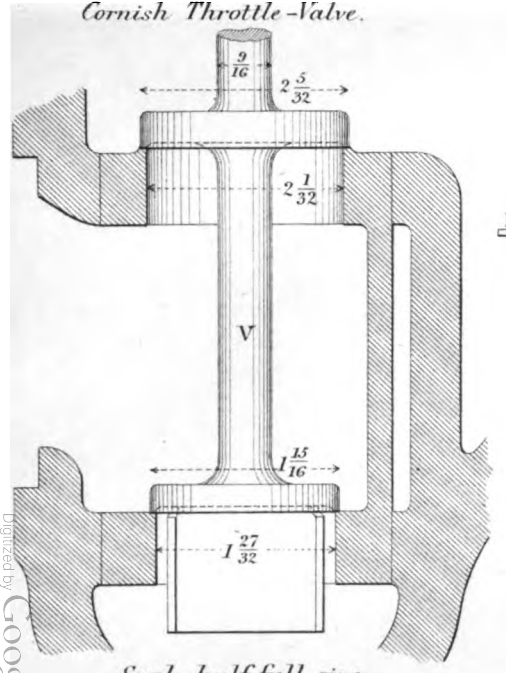
Fig 4. *Double-beat Cornish Throttle-Valve.*



Scale half full size.

(Proceedings Inst. M. E. 1885.)

Combined Electrical and Centrifugal Governor.

Fig. 5. *Front Elevation.*

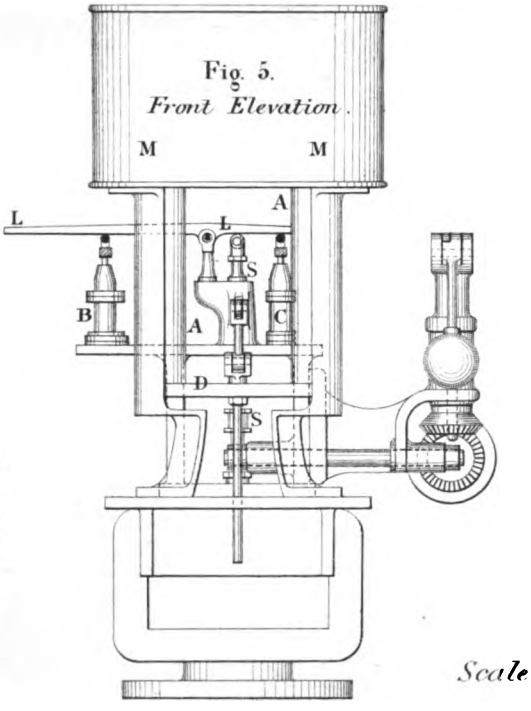
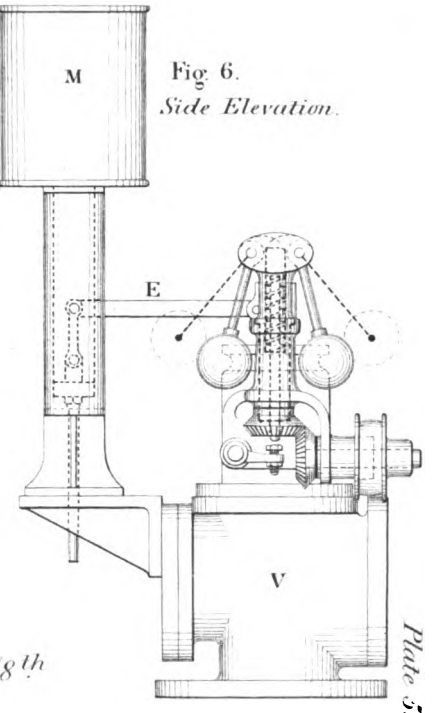


Fig. 6. *Side Elevation.*



Scale 1/8th

Ins. 12 9 6 3 0 1 Foot.

Plate 51.

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Fig. 7. *Plan of House and Premises.*

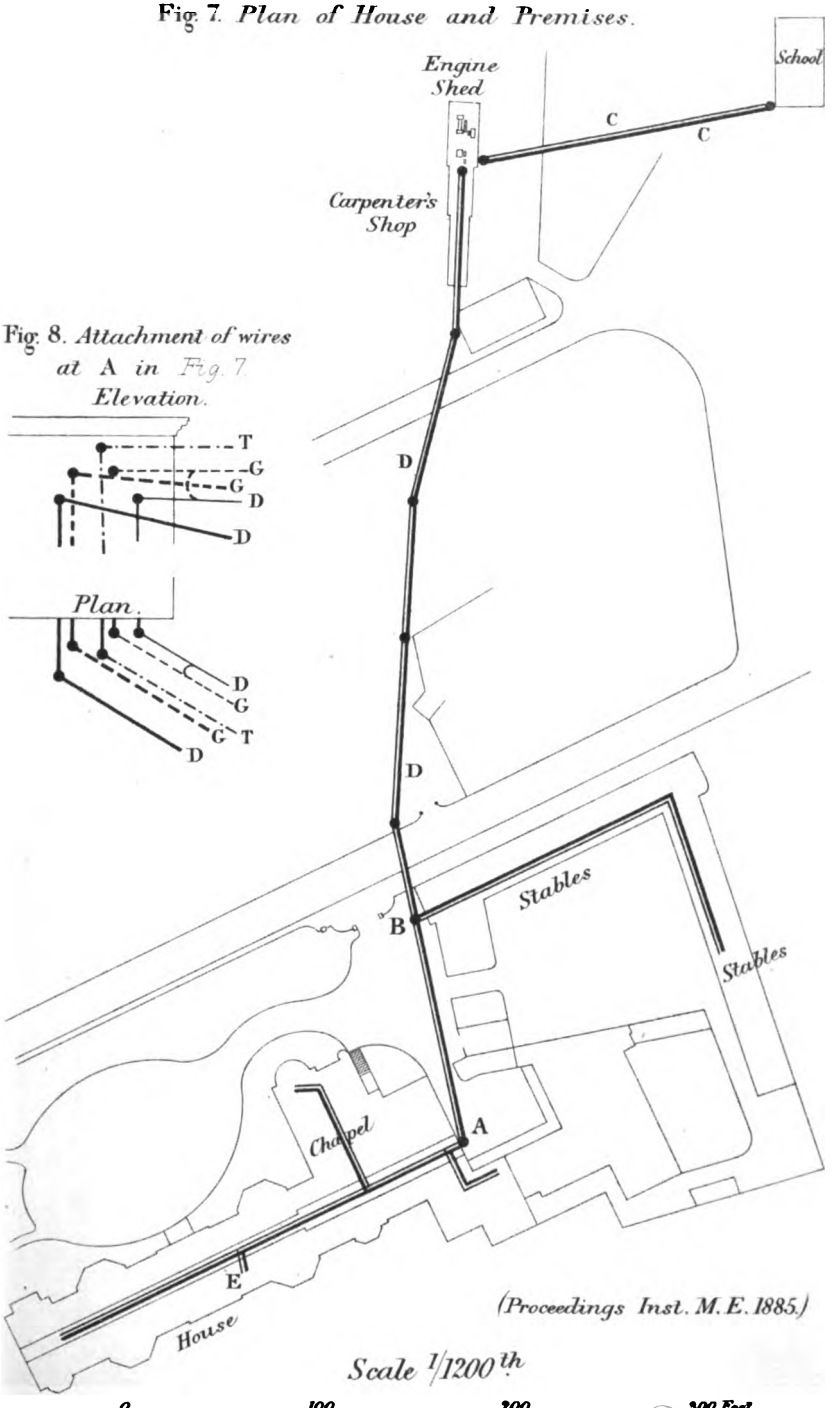

Fig. 8. *Attachment of wires at A in Fig. 7.*

Elevation.

Plan.

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Fig. 9. *Diagram of Installation for a Town.*

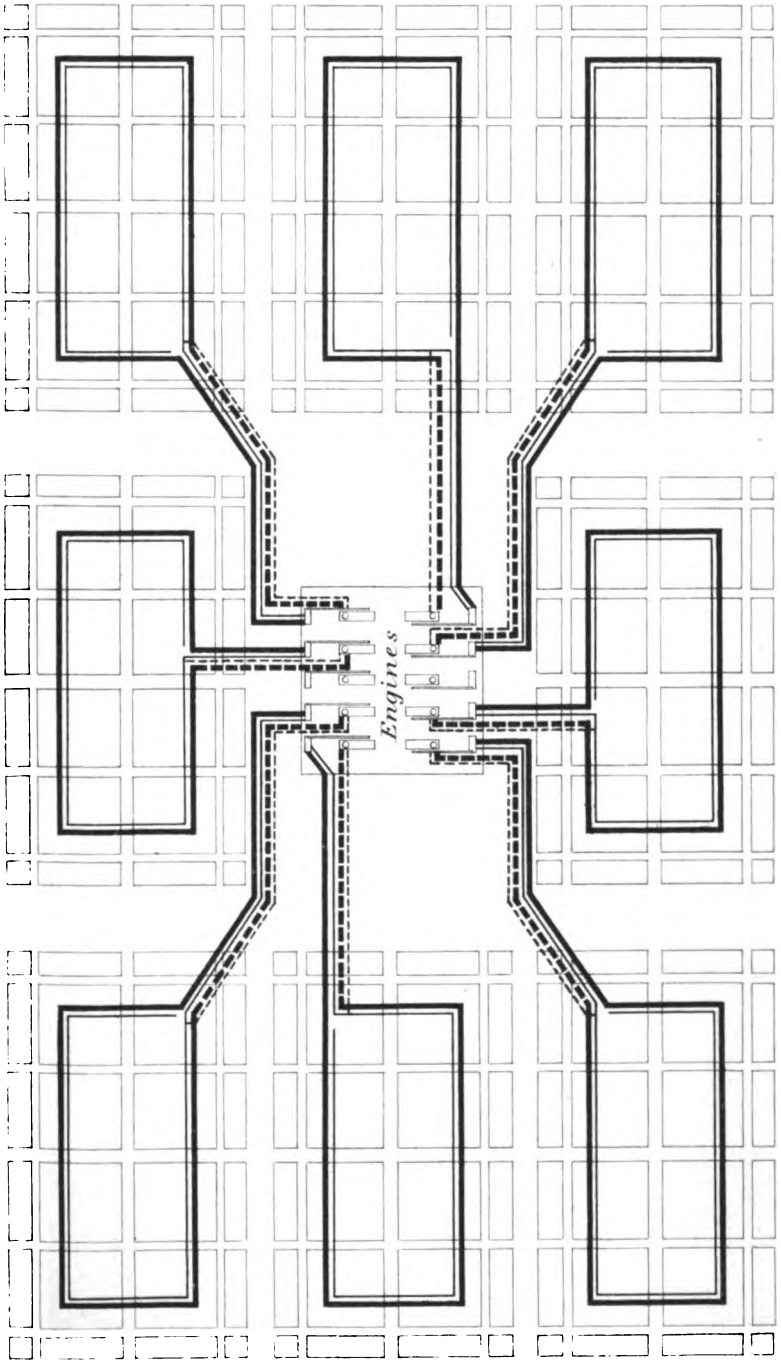

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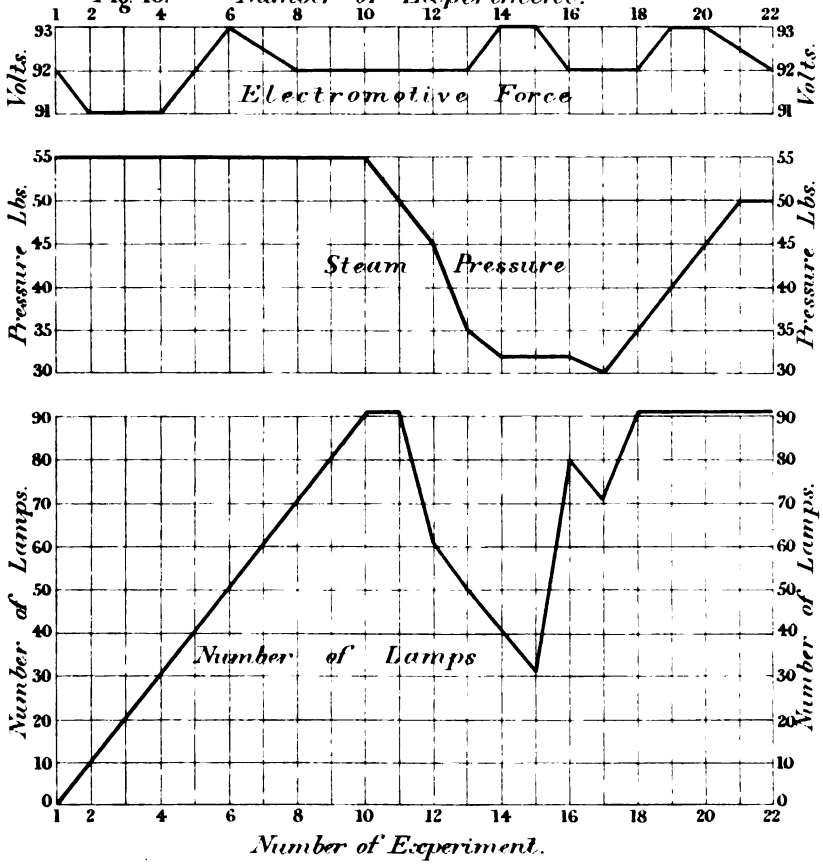
Fig. 10.


Number of Experiment.
1 2 4 6 8 10 12 14 16 18 20 22
Volts.
93 92 91
Electromotive Force
Pressure Lbs.
55 50 45 40 35 30
Steam Pressure
Number of Lamps.
90 80 70 60 50 40 30 20 10 0
Number of Lamps
Number of Experiment.

Diagrams showing upward force on Throttle-Valve Spindle

Fig. 11.

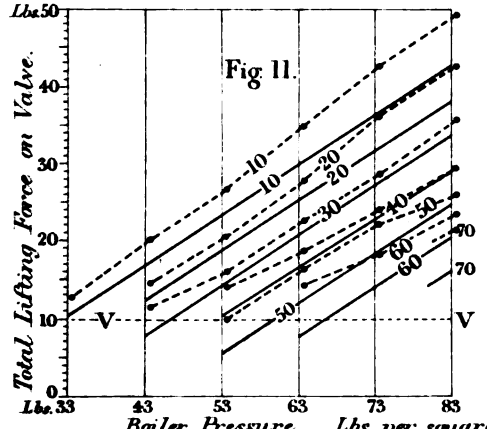
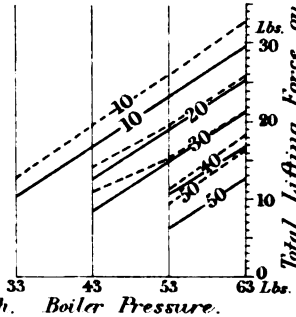


Fig. 12.



The figures on the oblique lines indicate the Steam-chest Pressure in lbs. per square inch.

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to the countershaft of the saw the latter can be driven by the engine when it is not required for lighting. The dynamo is driven direct from the fly-wheel of the engine by a 4-inch linked leather belt, which suits the purpose very well, there being no uneven places caused by lacing or other joint to occasion any unsteadiness in the running of the dynamo. Owing to the centres of the dynamo pulley and fly-wheel shaft being necessarily somewhat close together, the belt has to be kept rather tight when required to transmit the whole power of the engine. This however has never yet been required, except for experimental purposes.

The current generated is led from the dynamo to a set of switches, by which it can be distributed into five separate circuits. The first of these is the circuit exciting the field magnets of the dynamo itself. The second circuit furnishes lights for the engine-shed and the carpenters' shop adjoining, Plate 52. The third goes by the wires CC to a schoolhouse near. The fourth goes by an overhead cable DD to the house, as shown in Figs. 7 and 8, a branch being taken off at the point B to light the stables; the two dotted lines GG in Fig. 8 represent the wires returning from the house to the governor. The fifth circuit goes to a board, on which are fixed 100 lamps for experimental purposes; and this circuit is also intended to furnish current to secondary batteries or accumulators, which the author hopes to introduce before very long. The switches distributing these currents are two-way, so that the current can either be sent out direct, or can be passed previously through one of Ayrton and Perry's spring am-meters, whereby the amount of current in use on any one or more of these circuits can at any time be ascertained without causing any interruption in the light. The am-meter in use, being constructed to register up to only 20 ampères, has been provided with two shunts of thick german-silver wire, so that by using one or other of these the reading on the am-meter is reduced to one-half or one-third of the total amount passing; in this way the total current of 60 ampères can be registered.

The current for use in the house is led from the dynamo-room to the roof in an insulated cable of fourteen No. 16 wires (0·065

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inch thick), and is thence taken overhead through a bare cable of the same size, suspended on poles, to the point A, Fig. 7, at which it enters the house, where it is connected to a larger cable of nineteen No. 14 wires (0·085 inch). This cable has been provided in order to admit of a larger number of lamps being used in the house at some future time, without disturbing the wiring &c. inside the house. It leads well into the middle of the house, giving off on its way smaller branches to light sections of rooms; and then connects to a smaller cable, which again is reduced to a still smaller one before reaching the far end of the house. These cables all give off smaller branches to light the various rooms both up and downstairs. At their junctions with the mains the branches are fitted with fusible cut-outs, so that, in the event of any short circuit occurring of sufficient magnitude to cause any undue heating of the branch, the fusible plug would go, and would cut off that section. Most of the switches used have also fusible plugs in them, and are of the quick-breaking type, so that they cannot be left in such a position as to form an arc.

The lamps used are mostly 100-volt 20-candle-power lamps of the Edison and Swan make, each lamp using about 0·65 ampère; but in some cases two 50-volt 10-candle lamps placed in series are used, instead of one 20-candle lamp. This is principally the case in passages, which are thus better lighted by the greater diffusion of the light; and moreover it is never required to light one of these lamps without the other. In the chapel, Fig. 7, Plate 52, there is a hanging chandelier with twenty lamps, in which the current is conveyed to the lamps by the suspending wires; and the chandelier is so arranged that, for the purpose of replacing lamps which have failed, it can be raised or lowered without disturbing any connections. In most other cases the lamps have either been left simply attached to the ends of the wires, or have been fixed to the old gas-brackets. In the author's private workshop are a few lamps attached to flexible wires, which are very convenient for placing in various positions for working, and especially for turning.

The installation was first used in November last, and everything worked very satisfactorily with the exception of the governor, which

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proved utterly unsuitable, the inertia being so great that its position would remain the same for a very considerable variation of speed: so much so that, although an adjustable resistance of considerable magnitude had been inserted in the circuit exciting the field magnets of the dynamo, it was found impossible even with this to control the electromotive force to the point required. Frequently when resistance was inserted, thereby lessening the work done by the dynamo, the engine in consequence of the lightened load would increase its speed sufficiently to bring up the electromotive force to its old point. The consequence was that it was necessary to keep the steam pressure in the boiler almost absolutely constant, or rather to allow it so to vary in proportion to the load that it should keep the electromotive force constant. This was found exceedingly difficult in practice; and it was soon clear that it would be necessary to get some more efficient kind of governor. Having seen the working of Mr. Richardson's electrical regulator, and being much pleased with its principle of action and with its performance, the author decided to try it; and one was accordingly adapted to his engine. Although this old-fashioned type of engine does not lend itself very readily to the introduction of the necessary valve, the object was attained in a very efficient though possibly rather unsightly manner, by taking the steam from the top of the safety-valve fitting, and passing it through the throttle-valve actuated by the governor, and thence downwards into the steam-chest.

Electric Governor.—The regulating part of this governor, Figs. 1 to 3, Plate 50, consists of a double solenoid magnet MM, placed vertically and wound with insulated copper wire, within which works a double core AA; and to the cross-piece D at the bottom of the cores is linked the long arm of a lever E, the short arm of which presses downwards upon the spindle S of a double-beat Cornish valve V that controls the admission of the steam to the steam-chest. For incandescent lighting in parallel, the wire on bobbins is placed in shunt circuit between the main leads; and the size of wire used is adjusted according to the electromotive force which it is desired to maintain between the mains, so that when the electromotive force is at the

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right point the cores AA are suspended within the solenoids MM by their attraction. Inasmuch as the resistance of the solenoids is fixed, any increase in electromotive force causes an increased current to flow through them, whereby the cores are immediately attracted with an increased force, and are caused to move upwards, thereby acting through the lever E to close the valve until the electromotive force has been brought down again to its normal amount. The required movement of the valve V, Fig. 4, Plate 51, is exceedingly small; and this method appears to be the best suited for electric lighting. An automatic expansion-gear, on which the governor might be caused to act, has the disadvantage that, when but few lights are burning, the steam is cut off at so early a period of the stroke that unless the fly-wheel is exceedingly heavy a fluctuation occurs in the light during each revolution of the fly-wheel, somewhat analogous, though of course in a much smaller degree, to the unpleasant bobbing generally seen in electric lights driven by a gas engine where there are no accumulators. In a large engine, where economy of coal has to be considered, probably the best way would be to have an expansion-gear actuated by hand, which can be set approximately to the expansion required, leaving the throttle-valve to regulate the speed finally. But where perfect steadiness is desired, it is probably better not to cut off much before half stroke, especially if a single-cylinder engine is used. The use of accumulators as regulators would of course prevent a great deal of the fluctuation, and would permit of the steam being cut off much earlier without causing any apparent unsteadiness in the light.

The electric governor was fixed on the engine and worked for the first time on 13th January last. The improvement was remarkable, the lights remaining steady without the sudden alternations of brightness and dulness which had occurred before. But it was still found that with any considerable variation of boiler pressure or of load the electromotive force in the mains varied more than was thought conducive to long life in the lamps. As however it was found that, by augmenting or diminishing the weight H suspended from the core-bars AA, Fig. 1, Plate 50, the electromotive force

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could be brought back to its normal amount, it occurred to the author to fix an upright cylinder in direct communication with the boiler, and to make its piston-rod press upwards on the core-bars: the diameter of the cylinder being experimentally determined by observing the weight H necessary to be added or removed for certain variations in boiler pressure. This arrangement caused a very great improvement; and when the load was approximately the same, it maintained the electromotive force constant under very considerable variation of steam pressure. When however the load was varied very considerably, say from one lamp to a hundred, it was found that more variation took place in the electromotive force than was desirable.

The arrangement was accordingly modified, as shown in Fig. 1, Plate 50, by causing the piston-rod B communicating with the boiler to act upon a lever L, and by introducing a second cylinder C supplied with steam from the steam-chest, the second piston-rod acting upon the same lever but upon the other side of the fulcrum. The end of the lever was furnished with a steel knife-edge, bearing against another knife-edge set at right angles to it upon the prolongation of the core-bars. The cylinders B and C were also both of them made larger, and were placed so that they could either of them be moved nearer to or further from the fulcrum of the lever L, whereby the resultant effect of their differential power could be easily adjusted. This arrangement answered very well indeed, and it was found that the lights could be varied from 1 to 100 and the boiler pressure from 30 lbs. to 60 lbs. with but very slight variation of electromotive force in the mains: provided of course there was sufficient steam to do the work required. It is also quite easy to cause the electromotive force to rise as the load on the engine increases—or in other words as more current passes through the main—by simply giving greater leverage to the piston C connected with the steam-chest. In fact with this arrangement the electromotive force can be maintained practically constant, or can be made to vary in any desired manner with variations of steam-pressure or of load.

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The main leads to the house having a resistance of about 0·2 ohm, there is a loss of about 12 volts of electromotive force when 60 ampères of current are passing along them between the terminals of the dynamo and the house; whereas when only one or two ampères are passing, the loss is practically nil. Hence if the electromotive force were maintained constant in the dynamo room, it would fall at the house as more lights are turned on. In the case of an engine controlled by an isochronous governor, this difficulty is supposed to be met by the compound winding of the dynamo machine. There are however several disadvantages in that plan. One is that each dynamo ought to be specially wound for the electromotive force desired to be maintained, and for the external resistance between the lighting centre and the dynamo; and if either the electromotive force of lamps used or the external resistance is varied, the adjustment of the machine is destroyed. This also in a great measure prevents the use of reserve machines for a large installation where several circuits are used, because the reserve machines cannot suit all the circuits equally. Another disadvantage in a compound machine is that, if it be used in conjunction with secondary batteries and the engine be permitted to slow down before the connection between the dynamo and the batteries is broken, the current from these last will flow back through the dynamo, and will reverse the polarity of the magnets if it be a compound machine; and when next started, the batteries and dynamo will be wrongly connected, and considerable harm may ensue both to batteries and to dynamo.

The plain shunt-wound machine is free from these objections; but the disadvantage has hitherto been that, as more lights were put on, the electromotive force fell just when it should rise. With an electrical governor this can be obviated, as indicated above, by a suitable arrangement of the piston C, Fig. 1, actuated by the steam from the steam-chest. But a still better plan is probably that adopted by the author, of taking certain points as lighting centres, and keeping the electromotive force between them constant. For this purpose small wires are connected with the mains at the required points, and the current to actuate the governor is taken off there, instead of direct from the terminals of the dynamo. As seen in the

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plan, Fig. 7, Plate 52, one of the points is at A just outside the house, where the wires enter; and the other point is in a room marked E. The electromotive force between one cable at the point A and the other cable at the point E is maintained constant by the governor. The wire marked T in Fig. 8 is a telegraph wire communicating from the room E to the dynamo room.

This arrangement could easily be applied to a large installation for a town, each engine and dynamo having their particular district, somewhat as sketched in the diagram plan, Fig. 9, Plate 53. The cables would be led direct to each district, and governor wires as shown in dotted lines would be led back from the district to the engine governor. The arrangement of splitting up the required power into several small engines, instead of employing only one or two very large engines, permits of this plan; and also requires very much less reserve of power to provide against a break-down. For example, if the lighting of a town be estimated to require 2000 I.H.P., and this be divided between two engines of 1000 I.H.P. each, it will be necessary to have either one or two similar large engines in reserve, according as it is intended to provide against a single or double break-down. If however the same power be divided amongst forty engines of 50 I.H.P. each, it will only be necessary to have a reserve of one or two of these smaller engines for providing against similar contingencies. A simple arrangement of switches would then at once permit of a reserve engine with its regulator being switched on to any particular circuit on which it might be required, owing either to a temporary break-down or to a special extra demand for current.

Another advantage of an electrical governor over any arrangement of isochronous governor, however perfect, is that the electrical regulator takes its regulation from the mains, and not from the engine; consequently if there be any loss, either by slip of belt, or by extra heat in the field-magnet circuit or the armature, causing increased resistance, this will be compensated by the electrical governor at once driving the engine so much faster as to make up for it. On one occasion when experimenting with the governor, this was specially noticeable; for when the load got rather heavy, the belt at the time being rather too slack, the engine suddenly

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increased its speed considerably, but the volt meter remained at the same point, and the dynamo was found to be running at just about its ordinary speed, the extra speed of the engine being evidently caused by slip of belt.

When the lever arrangement was completed, several experiments were made by Mr. Richardson and the author, the results of which were as follows. When the load on the engine was allowed to remain constant, with only one lamp alight, it was found that while the steam pressure was allowed to vary between 31 lbs. and 55 lbs. the electromotive force remained constant at 90 volts. Afterwards, with the same extent of variation in steam pressure, and with the load also varying from 1 lamp to 91 lamps, the electromotive force varied only 2 volts, namely from 91 volts to 93 volts. The following are the particulars of this second set of trials :—

Steam Pressure. lbs.	No. of Lamps.	Electromotive Force. volts.	Steam Pressure. lbs.	No. of Lamps.	Electromotive Force. volts.
55	1	92	45	61	92
55	11	91	35	50	92
55	21	91	32	41	93
55	31	91	32	31	93
55	41	92	32	80	92
55	51	93	30	71	92
55	61	92½	35	91	92
55	71	92	40	91	93
55	81	92	45	91	93
55	91	92	50	91	92½
50	91	92	50	91	92

These twenty-two experiments are also plotted graphically in Fig. 10, Plate 54, in which the bottom line shows the variation in the number of lamps from 1 to 91; the middle line shows the variation in the steam pressure between 30 lbs. and 55 lbs.; and the top line shows the consequent fluctuation of only 2 volts in the electromotive force, namely from 91 volts to 93 volts.

The arrangement of the governor has since been modified, as shown in Figs. 2 and 3, Plate 50, in order to obtain a neater looking arrangement and also better results. Here there is also the

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advantage that, if an ordinary centrifugal governor be added to the engine—which *may* be done as a measure of safety, in view of a wire breaking or of the main driving-belt coming off: and which *must* be done if the engine be required to do other work, such as sawing or pumping, at times when the dynamo is not running—the throttle-valve will still be compensated by the lever L, Figs. 2 and 3, which would not be the case if the compensating arrangement were attached only to the solenoid as in Fig. 1. Front and side elevations of the combined electrical and centrifugal governor are shown in Figs. 5 and 6, Plate 51.

In the diagram Fig. 11, Plate 54, is shown the variation in resultant upward force on the valve-spindle, caused by different pressures in the steam-chest and boiler. This upward force acting on the valve, as ascertained experimentally by actual measurement, is represented by the series of dotted curved lines; and the full straight lines close below the dotted lines represent the calculated counteracting force exerted downwards on the valve-spindle by the compensating arrangement. At any boiler pressure therefore the vertical distance between a dotted line and its corresponding full line shows the net force which has to be governed by the electrical arrangement. In practice a weight W, Figs. 1 and 2, Plate 50, is adjusted upon the compensating lever L, for preventing the differential lifting force from ever becoming zero, as it is seen to do in Fig. 11 at 40 lbs. steam-chest pressure with 83 lbs. boiler pressure; otherwise the valve would then close. For the sake of clearness however the diagram has been plotted without this weight, which does not affect the principle; the addition of the weight would simply move the lower line still lower down, parallel to itself, leaving the *variation* of difference the same. If the compensating arrangement were absent, the force which the governor would have to counteract would be represented by the whole distance down to the horizontal dotted line VV, which is drawn rather above the zero line for indicating what is practically the least upward force that there would ever be on the valve when the engine is running, namely about 10 lbs. total lifting force.

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In diagram Fig. 12 is shown simply a similar set of lines for the same valve, but not extending to such extreme differences as in Fig. 11; and by a slight difference of adjustment in the leverage of the pistons of the compensating arrangement the compensation is rendered still closer. In the first diagram, Fig. 11, the maximum difference shown is 6 lbs., and in the second, Fig. 12, it is only 3 lbs.; and as the solenoid used has a pull of about 25 lbs. with an electromotive force at its terminals of 100 volts, while a variation of 1 volt causes a variation of about 4 lbs. in the pull,* the maximum difference in the electromotive force ought not to exceed 2 volts in the first diagram, or 1 volt in the second. When the cores of the solenoid are in the most favourable position, the difference of pull caused by a small movement of them is very slight; and the movement required to open or close the valve is very small. Through a valve similar to the one shown in Fig. 4, Plate 51, steam sufficient to indicate 55 HP. has been passed with a lift of only 0·1 inch, and with a difference of less than 5 lbs. between the pressure in the boiler and that in the steam-chest.

When it is desired to vary the electromotive force in the mains, a set of adjustable resistance-coils is inserted in the governor circuit; by increasing these resistances, a higher electromotive force is required to drive the normal current through the solenoid, and thus to close the valve. In this way the speed of the engine and the electromotive force in the main wires may be varied to almost any required extent, and from a point however distant from the engine. The author has one set of these coils fixed in the circuit in the dynamo room, and another at the point E in the house, Fig. 7, Plate 52; and by moving either of these the resistance may be increased or diminished, producing a corresponding variation in the electromotive force. This is found a great convenience when exceedingly exact electromotive forces are required for experimental

* The pull here referred to is that on the valve-spindle, as explained in the discussion (pages 403 and 407), the corresponding pull at the magnet end of the lever being 0·4 lb. with a leverage of ten times.

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work, which sometimes cannot be carried on in the immediate neighbourhood of the dynamo machine. It may also be arranged practically to dispense with the necessity of any telegraph or signal to the engine-room, because a switch and set of coils placed in any convenient position afford the means of varying the light as desired, without any reference to the engine-driver, whose work then consists simply in seeing that sufficient steam and water are maintained in the boiler, and that all bearings are kept duly oiled.

In the case also of an engine doing any other work, where it is desired to vary its speed from a distance, the same governing arrangement may be applied by causing the engine to drive a small dynamo just sufficient to furnish electricity for the electrical regulator. The electromotive force in the mains would then furnish at any desired point an indication of the speed of the engine at any moment; and a switch and set of resistance coils would afford the means of altering the speed to any other desired rate. As the amount of current required for driving the regulator is only small, the coils and switch may be made very small and compact; so that in a theatre, for example, they might be placed in the prompter's box, and the whole system would then be under his immediate control. It may also be applied to govern an engine pumping into a reservoir, the water as it rises in the reservoir being caused to vary the resistance in the governor circuit by means of a float; so that the higher the water rises, the slower will the engine go.

The introduction of this governor has in the author's opinion contributed very largely to the duration of the lamps used. From the first start until the end of last year the time of running was 370 hours; and during that time with the old governor five lamps gave out, although they were all new when the installation was started; the average current during that time was 16 ampères. Up to 13th January last, when the new governor was first introduced, the time of running was 477 hours, and thirteen lamps had given out; probably also many of the others had been damaged. Nevertheless during the 487 hours' running in February, March, and April, although the average current used had increased owing to the extension of the installation, only ten lamps gave out; and during the 84 hours' running in June only two lamps gave out. Hence

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it appears that a good governor will soon save its own cost by an increased life for the lamps.

Thus far reference has been made solely to incandescent lighting in parallel; but for arc lighting in series the advantages of a governor of this description are very conspicuous. Probably the best system of driving arc-lights in series is by the use of a series-wound dynamo, especially if a compound engine be used for the purpose, because then the steam-chest pressure remains approximately constant, and the speed varies approximately in accordance with the number of lamps in use. Here an isochronous governor is obviously altogether useless. An electrical governor however meets the case perfectly; the whole of the current to the lamps is led round the solenoids, which are of course made with fewer coils of a thicker wire. When any lamps are short-circuited, a momentary increase of current takes place, which instantly raises the cores in the solenoids, and shuts off the steam, reducing the engine to the required speed for the number of lamps left on. The following are particulars of some experiments made in 1883 by Professor Thompson, of University College, Bristol, with a machine of this description, showing the fluctuations in the current with different numbers of lamps alight:—

	Ampères.	Ampère.
Lamps alight 0 . . .	Current 10·6 to 11·2 . . .	Fluctuation 0·6
5	10·0 to 10·5	0·5
11	10·0 to 10·3	0·3
16	9·9 to 10·2	0·3
17	10·1 to 10·2	0·1

The greater unsteadiness noted in the first two experiments was due, not to any defect of the governing arrangement, but to the very slow speed of the dynamo, the strength of the current being distinctly varied as each section of the armature passed the magnets. The time tests showed that, when the full number of lamps were burning and five at a time were switched off, the engine immediately adjusted itself to its reduced speed, the current necessarily rising momentarily, but returning to its normal value in less time than could be measured.

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Before the introduction of this regulator, very considerable trouble was experienced in keeping the speed at the proper point, and many of the fine-wire coils of the Brush lamps were destroyed by an excess of current going through the circuit. Now however the current has been effectually controlled, and any number of lamps can be switched in or out without any attention being paid to the engine. Here also an arrangement is introduced, as shown in Fig. 1, Plate 50, by which, should the main lead become accidentally severed, the engine is at once stopped. A small electro-magnet N is introduced, round which the current is led with a few turns of wire. The magnet supports a weight G of several pounds, which is attached to a lever R so pivoted that, when on the cessation of the current the weight falls, the lever presses with great force on the top of the valve-spindle, and shuts off the steam altogether.

Discussion.

The President said that, as the two papers just read by Mr. Richardson and Mr. Nevile would now be discussed together, he would ask the authors to make any additional remarks which they might desire to make before the discussion commenced.

Mr. Richardson said the fact of his present paper forming a continuation of the one which he had the pleasure of reading twelve years ago at Penzance would be sufficient to account for its limited extent. The extensive criticism which on that former occasion had been bestowed upon the portable engine in the mining districts of Cornwall had been very instructive; and notwithstanding its generally unfavourable tone, the portable engines then already in use there had held their ground, and had been used in increasing numbers there to the present day.

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(Mr. Richardson.)

As a practical illustration of the expedition with which the semi-portable winding engine with wrought-iron foundation could be put together, he had given orders only yesterday afternoon that one then packed up and loaded on a truck standing on the railway should be unloaded and put together and got ready for the members to see under steam in visiting the works this afternoon; and this had been done before eight o'clock this morning, with its winding gear complete.

Referring to the electrical governor, he wished to call attention to the smallness of the variations of current shown in Professor Thompson's experiments given in page 388 of Mr. Nevile's paper. To any practical electricians among the members present he should be glad to show the engine that had been experimented with in driving the lights during those tests; and to any one interested in the subject he should be happy to afford the opportunity of trying the experiments for himself, when it would be seen that the fluctuations, which amounted to only six-tenths of an ampère, lasted only as long as would be required to open the eyes and shut them again. The fluctuations in current occurred just at the moment of turning off the lamps; but they subsided immediately, and it was a matter of only a few seconds before the current returned to its normal state of uniformity.

Mr. NEVILE mentioned that since writing his paper he had had practical experience of the method of driving the electrical apparatus from the house. About a fortnight ago he gave his engine-driver a week's holiday, and put one of the carpenters, who had been accustomed to drive the engine for sawing, to drive the electrical apparatus. His simple orders were to keep enough steam and water in the boiler, and see that the bearings were duly oiled. During the whole of that time the engine was driven from the house by himself, by means of the switch arrangement situated at E in the plan, Fig. 7, Plate 52. In this afternoon's visit to Messrs. Robey's works would be seen the centrifugal part of that governor driving an engine with a compensating arrangement attached to it. There was no suitable dynamo available for the purpose of driving it; so that

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the electrical arrangement could not be shown at work, but the centrifugal arrangement would be at work with the compensating arrangement attached.

He exhibited a specimen of the combined centrifugal and electrical governor, and showed how either the centrifugal or the electrical portion could work independently of the other, and how they both worked also in conjunction. When the electrical governor was at work, the short arm of its lever pressed down upon the top of the valve-spindle. When the centrifugal governor was at work, it acted in the usual way through a lever, of which the short arm worked in a slot in the spindle, immediately underneath the lever of the centrifugal governor, and pressed downwards on the spindle. When they were both working together, the electrical governor took the entire control from the centrifugal governor, so that the arm of the latter was just free in the slot, not pressing down upon the valve so long as the electrical governor was doing its work. If the electrical governor failed, owing to a wire breaking, or anything of that sort happening, a slight increase of speed would take place, and the centrifugal governor would take charge of the regulation and would stop any further increase. The spindle of the valve was so packed that the valve always fell by its own weight when there was no steam pressure, showing that there was practically no material friction in the stuffing-box; there was no difficulty in packing it so that it should drop by its own weight, and yet that there should be no escape of steam of any consequence.

With the electrical governor the difference in the force of pull in a short movement of about an inch at the magnet end of the lever was so little that the two adjusting cylinders, acting upon the compensating lever, had merely to overcome the variation of the pressure upon the two faces of the valve. When there was a centrifugal governor, they required to be set out further apart on each side of the fulcrum, so as to give them more power, because then they had not only to overcome that variation, but also to overcome to a certain extent the resistance of the spring in the centrifugal governor; therefore their points of adjustment along the compensating lever were not exactly the same, when there was a

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(Mr. Nevile.)
centrifugal governor in addition, as when the electrical governor alone was used. But of course in driving an apparatus for electric lighting, it was in the electrical portion that care was taken to get perfect steadiness; and then, if in addition the engine were driving also a pump or saw bench or any machinery of that sort, it did not matter if the speed did vary a little. Even then the speed did not vary more than about 2 per cent.; indeed he doubted whether the variation was as much as that.

Mr. R. E. B. Crompton observed that a subject of great importance had been touched upon in the paper, where it set forth that the principle of electrical governing would enable the electromotive force to be controlled at points very distant from the engine-room; and consequently would enable large districts to be supplied at great distances from the lighting centre, as sketched out in the diagram Fig. 9, Plate 53. All that was said in the paper in relation to Fig. 9 had been set forth at great length by Professor Forbes in his Cantor lectures at the Society of Arts in the present year; also a long paper on the subject of the electrical governing of engines had been read by Mr. Willans before the Institution of Civil Engineers this year; and accordingly the views advanced on this subject in the present paper could not be regarded as novel or unknown to electrical engineers.*

Turning to the particular electrical governor described in the present paper, he confessed his inability to understand it. Having been experimenting for two years on this subject in correspondence with Messrs. Willans and Hartnell, they had found that, although electricity seemed to be a very efficient means of actuating governing mechanism, yet if it were used in the form of a current powerful enough to work large solenoids operating the throttle-valve direct, the operation was such a wasteful one as to be practically out of the question. This consideration of economy forced them to deal with a very small current for effecting the result required. Experiments

* Journal of the Society of Arts, 1885, pages 257, 289, 313, 1027; and Proceedings of the Institution of Civil Engineers, vol. lxxxi, page 166.

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on the friction of the throttle-valves and their gland-packing in ordinary steam-engines had shown that a large margin of power was necessary to move such valves with ease and certainty; in some cases it was found that the difference between the valve-rod being well packed and rather badly packed amounted to 30 or 40 lbs. end pressure. With the leverage of ten to one, shown in Fig. 3, Plate 50, the solenoids would have to exert a pull of 4 lbs. on the long arm of the lever in order to give 40 lbs. pressure on the valve-spindle. In addition it was stated in the paper that the maximum difference between the full and the dotted lines shown in Fig. 12, Plate 54, was equivalent to 3 lbs. pull; therefore he believed that frequently a total pull of 7 lbs. would have to be exerted by the solenoids for actuating the valve, and this 7 lbs. pull could not be obtained from the solenoids in moving through a distance of even as much as one-tenth of their full stroke. The total pull of the solenoids being given as 25 lbs., it followed that, taking even the lower difference mentioned of only 3 lbs. in the pull, the solenoids would have to exert in moving through only one-tenth of their stroke a difference of pull amounting to no less than one-eighth of their total pull. This he could not believe to be the case; it was contrary to all experiments made by himself and by many others, in which it had been found that the available pull in a solenoid, caused by variation in electromotive force within the range allowable, was not more than one-eightieth of its total pull: so that the paper represented the pull as ten times that which he had found in practice to be obtainable. In all other attempts at electrical governors the solenoid used as a means of directly actuating the throttle-valve had been abandoned, whether supplemented by the compensating device or not. The compensating device certainly appeared to him to be extremely ingenious; taken by itself it appeared to act as a higher order of reducing-valve doing part of the work of a governor; and in fact it seemed to him that, if the compensating cylinders were as well arranged as they could be, the solenoid would practically have very little to do. But he objected to it as a complication, which after all was theoretically speaking very imperfect.

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(Mr. R. E. B. Crompton.)

In other plans of electrical governing, the electricity actuated some more powerful mechanism, which again actuated the main slide-valve: the solenoid for instance moving the very tiny slide-valve of a water or steam or oil cylinder, of which the main piston or plunger worked the larger valve. This had been effectively carried out by Mr. Willans, who had been most successful in controlling the independent action of the two slide-valves, small and large, by cross-coupling them, so that for every position of the solenoid core there was a corresponding relative position of the main throttle-valve; and this prevented the hunting or pulsating movement which would occur if they were independent of each other. From his own knowledge of the Willans governors, of which he had used a large number, he could state that, instead of the pull of only 3 lbs. as provided in the present paper for working the main throttle-valve, they always provided for a pull of 40 lbs., and sometimes of 60 lbs.; and in working turbines or water-wheels the governor exerted a pull of one ton on the throttle-valve spindle, or on what answered in a turbine to a throttle-valve spindle. These heavy pulls were obtained by the use of mechanism which had no more parts in it, and was no larger in any way, than the governor now exhibited, but which took less than one-fourth of the electrical energy to work it.

Mr. Illius A. Timmis said the only question upon which he would offer a remark in reference to Mr. Nevile's paper was the use of the solenoids in connection with the governor. The slight mention which had been made parenthetically by Mr. Crompton of a small current contained the gist he thought of a great argument. If a small current were used with a high electromotive force, it only came to the same thing practically as using a large current with a low electromotive force. Speaking subject to correction, he thought this was rather what Mr. Nevile was aiming at with his solenoids, namely to use a large current with a low electromotive force for working the solenoids which were employed to adjust the governor.

The spring am-meter had been mentioned in page 377 of the paper as being used as a tell-tale of what was going on during the running

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of the whole system. From a number of experiments that had recently been made on am-meters he believed that before long an am-meter would be introduced, which would at the same time do for a volt meter. There would be no spring of any kind in it, and therefore it would not measure mechanically, though of course there would be mechanical registration. It would not only measure the current running, and by a slight adjustment the volt force also, but it would enable the user to employ it as an adjuster, and in fact as an electrical governor. This new am-meter he thought was the very essence of simplicity, and would enable Mr. Nevile to simplify very considerably the arrangements which even now he had worked out so admirably.

For two or three years he had now been working very carefully and in different parts of the country the Faure-Sellon-Volkmar accumulators; and with the later patterns which he had been working for the last twelve or fifteen months he was more than satisfied. In one battery of the very latest pattern, which had been working for eleven months, he had not long ago tested the plates, and he did not think there was any difference between them as they existed now and as they were when quite new. Practically that battery would last for a very long period; and he had the authority of Professor Forbes for saying that he did not know what the duration of the present Faure-Sellon-Volkmar cells would be. This was a very important feature; for however nicely governors might be adjusted, some slight fluctuations must be looked for. But if a battery could be obtained that would absolutely do away with all fluctuations, and would last so long, its first cost would be minimised, while perfect steadiness would be realised. In mentioning accumulators, page 377, the author seemed to him to have done wisely; and he hoped that in his future experiments he would, not only for his own sake but also for the general interest, pay some attention to their working.

Mr. Sydney F. Walker thoroughly agreed with all Mr. Nevile had said about the life of lamps depending on the constancy of the electromotive force; in his own experience there could not be any mistake about that. The life of the lamps was directly as the constancy of the electromotive force. Five minutes' strain might

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(Mr. Sydney F. Walker.)
take a hundred hours out of the life of the lamps; and even a sudden decrease of speed, by the induced current which was sometimes a source of trouble, might strain the lamps.

With regard to the electrical governor described in the paper, he had had the pleasure of seeing it working at Messrs. Robey's, and could confirm all that the author had said about it. Though he had not seen the Willans governor, he had read descriptions of it; and he certainly looked upon the one now described as by far the simpler, so long as it was without the compensating arrangement. Any such compensating arrangement, by taking away from the simplicity of the governor, rather detracted in his opinion from its utility. Between large installations such as were illustrated in the diagram, Plate 53, requiring 1000 or 2000 horse-power, and the private installations which formed the subject of the paper, he thought a broad distinction should be drawn. In large installations every effort had of course to be made for securing in every possible way efficiency: that is, for obtaining as great a return as possible for every pound of coal expended. But in private installations his own experience was that it was often a saving to sacrifice efficiency in that respect to simplicity; and he should therefore prefer to use a little more power in the governor, by making the solenoid a little larger if necessary, and so to get rid of the complication of the compensating arrangement. The solenoid or some similar arrangement he looked upon as simpler and therefore better than any arrangement in which there were two or three different forces acting. One of the greatest difficulties in obtaining success with a new thing was to get a competent man to look after it. With the Willans governor the same man was required to take under his control steam, electricity, and a hydraulic cylinder; and at the present time it would be found difficult he thought to get a man at the ordinary rate of an engine-driver's wages who could be trusted to look after all that. At the same time he thought that for private installations it was only fair to say that all that had been done with the electrical governor described in the paper might have been done with an ordinary mechanical governor and a compound dynamo. In his own experience he had had no difficulty in getting steady successful lighting with any well-

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made engine, if he could be sure of two things:—a plentiful supply of steam, and a quick-acting governor which would cut off very sharply upon a very small increase of speed in the driving shaft.

It had been very fairly pointed out in the paper that the electrical governor did what no mechanical governor so far as he knew would do: namely, give a rising speed to a rising load and a falling speed to a falling load. No mechanical governor he believed would do that; but in this case all that was required might have been obtained at less cost, he thought, by increasing the size of the lead wires from the dynamo-room and from the house. For practical purposes, rather larger wires would have rendered the rise and fall of potential inappreciable.

What was to be done with the compound dynamo he thought was as yet hardly appreciated. The compound dynamo, like electrical science itself, was at present in its infancy. Engineers had only begun to use it, and hardly knew yet what could be done with it. Properly arranged, it appeared to him that it might be constructed to do all that the electrical governor could do at a constant speed. It might be constructed to give a constant electromotive force with a constant speed, a rising electromotive force with an increasing number of lamps, a falling electromotive force with a decreasing number of lamps, and a constant current with a falling electromotive force in the case of arc lamps in series; and it also appeared that it would do what was not an easy matter, though this had still to be worked out—namely, provide a constant electromotive force with a fairly constant number of lamps and at varying speed.

As to the use of accumulators, he was by no means convinced that this would be the best plan for private lighting. He should himself prefer some such arrangement as Davey's motor, which he understood, when filled with a charge of coal and water, would run for nine hours without attention. The great difficulty in getting success in electric lighting was to get a suitable man to look after the apparatus; and where ten men might be found who could look after an engine, there would be but one he thought who could look after accumulators.

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Mr. Druitt Halpin asked at what speed the indicator diagrams shown in Fig. 15, Plate 49, had been taken from the compound semi-portable engine. From the appearance of the low-pressure diagram he gathered that there was a separate cut-off valve for the low-pressure cylinder. The use of such a valve was never very clear to him, especially in an engine of low power; but certainly, if such good diagrams could be got from it as those now shown, it was more than might have been expected. They were the most beautiful diagrams he had seen, and there was only one question that occurred to him with regard to them. The initial pressure in the high-pressure cylinder was given as $92 + 13 = 105$ lbs. above the atmosphere, while the boiler pressure was 120 lbs., which made a drop of 15 lbs. between the boiler and the cylinder; that was rather a heavy drop, considering that the boiler was close to the cylinder. On the other hand there was the remarkable fact that the exhaust line of the high-pressure cylinder was a perfectly straight line at 13 lbs. above the atmosphere, while the initial pressure to the point of cut-off in the low-pressure cylinder was also 13 lbs.; so that there was no drop at all between the two cylinders, in contrast with the 15 lbs. drop from the boiler to the high-pressure cylinder.

In regard to the question of governing by electricity, he quite agreed with Mr. Crompton that it was advisable to interpose some kind of intensifier, such as was already used for similar purposes, so that the governor had so to say merely to do the work of thinking, leaving some other mechanical power to do the heavy part of the work. A combination of steam, electricity, and hydraulic power had been spoken of for doing the work; but he did not think that any such complication was at all necessary. Probably the hydraulic part might be got over by simply taking water from the boiler, so as to get the boiler pressure without the jumping which would attend the use of steam, and which would involve the addition of a second cylinder for controlling the motion. To his mind the use of an electrical governor was not perfectly clear. If it was desirable to vary the speed of the engine, there might of course be occasion for the application of a contrivance of that kind; but as long as the requirements of the case admitted of keeping the speed of the

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engine constant, he thought mechanical engineers could do very well without an electrical governor. In the case of a large compound tandem engine, made by Messrs. Hick of Bolton, having 16 and 30-inch cylinders with 36 inches stroke, and running at 100 revolutions per minute, for lighting the city of Temesvar in Hungary, the engine ran in winter fourteen hours, and at midnight the lights were turned down, so that the power developed was reduced from 200 down to 100 I.H.P. The engine was running with a Knowles supplementary governor in connection with a Moscrop recorder, so that the records were automatically taken and were beyond dispute. The maximum total variation in the speed was only one-third of 1 per cent. during the fourteen hours. Where the change was made at midnight it was impossible to see from the diagram record. The result of the excellent mechanical governing and the steady driving in that instance was that the lamps had already run between 2000 and 2500 hours, and they were by no means at the end of their life yet; in fact he did not know what the limit of their duration would be.

Mr. John P. Fearfield mentioned with regard to electrical governing that he had put up several dynamos which had to be driven by the same engine that drove lace machinery. Having had to erect a great many engines for driving lace machinery, he could state that the great difficulty had been to maintain uniformity of speed, because the working of lace machines would not admit of any variation of speed. The load on an engine in a lace factory varied very little less than the load upon a rolling-mill engine. With an engine built by Messrs. Hick he had himself indicated 100 H.P., and within a minute only 18 H.P.; and the variation in speed, as tested by a Moscrop recorder, amounted to only 1 per cent. Another engine was now building by Messrs. Adamson, which was designed not to vary more than $\frac{1}{2}$ per cent. If this could be done for a lace manufactory, he thought it would be agreed that an engine could be made to drive at any specified speed for electric lighting without any need of an electrical governor. He might also mention that Mr. Crompton, who had refrained from saying it himself, could

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(Mr. John P. Fearfield.)
construct a compound dynamo which would maintain a certain electromotive force constant within 1 per cent., provided the speed were not varied. At his own works he was running three of Mr. Crompton's dynamos and two Gramme machines. With the Gramme he had had a difficulty in governing; in fact he had put a resistance in the current that went round the shunt winding, and according to the variation of the load the engineer had occasionally to look at the volt meter and alter the resistance in the current running round the shunt. It would be found that most persons who were putting up electric-lighting apparatus were doing so for the reason that they had an engine running already, and therefore had plenty of spare power; but few would be at the expense of putting up special engines. Therefore what was wanted from electrical engineers was a governor that would govern the dynamo, as was done in many instances in America, by shifting the set of the brushes round the commutators; or, as he had proposed to Mr. Crompton last year, a reliable and practical governor that would alter the resistance of the shunt coil, and thus alter the quantity of electricity going out to the lighting circuit.

Sir James N. Douglass said that, having himself been connected with electric lighting for the last thirty years and maintaining arc lights for the last twenty-eight years, he desired to congratulate Mr. Nevile on the pains he had taken, not only in preparing the excellent descriptive paper which had been read, but also in carrying out his own private installation. Incandescent lighting alone had been dealt with by the author; and although both that and arc lighting were very important, and there was a promise of great work in them both, at the present time he thought the most important subject to mechanical engineers, and especially in the lighting of factories &c., was arc lighting. With regard to cost, his own experience had been confined to light-house work, and perhaps that was one of the best applications of arc lighting; next in importance was perhaps the lighting of steam vessels; and the next was the lighting of large factories. At the present time incandescent lighting was barely holding its own financially against gas or oil. With arc

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lighting fully four times the amount of light could be produced per pound of coal consumed that could be produced with incandescent lighting; and consequently at the present time any factory could be lighted by arc lights at less than half the cost which would be involved in lighting by oil or gas. The only disadvantage in the system of arc lighting was the difficulty of distribution; but then it would appear that distribution was really of no consequence. He had been in large factories lighted by half a dozen arc lamps, where there had been perfect lighting without any distribution beyond those half dozen centres of light and a judicious utilisation of all available white surfaces for reflection. When he commenced electric lighting, the best arc light that could then be produced was 670 candles, and it was very unsteady indeed; now they were working up to 30,000 candles, and the light was perfectly steady. Great improvements and developments had occurred with dynamos and lamps; but perhaps not the least of all had been in the carbons. Having begun with the common carbon taken from the residuum of gas retorts, they had now splendid carbons, uniform in quality; and the consequence was that a good arc light was now as steady as the light of a candle.

The perfect regulation of the lamp was of course closely connected with the question of the governor. An electrical governor was not a contrivance to be disparaged by mechanical engineers; indeed he believed the time was coming when no engine would be considered to be perfectly controlled without an electrical governor. Electricity seemed the nearest approach to the human mind in the instantaneousness of its action; and it could be used for the purpose of governing an engine without any appreciable loss of power. Reference had been made to its use as involving a loss of power, which he did not altogether realise. The electric lamps of Dubosc, Holmes, and Sellon, were all perfectly controlled without any appreciable loss of power, merely by a current passing to the solenoid, and thereby regulating the closeness of the carbons by releasing an escapement, the actual power which effected the adjustment being the weight of the upper carbon itself. In an electrical governor all that was required was a weight corresponding with the power which was necessarily absorbed, as referred to by Mr. Crompton.

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(Sir James N. Douglass.)

The electrical governor had only to be provided with that weight, either by steam from the boiler, or by water pressure, or by a falling weight, and the engine might then be controlled with a minimum amount of electric current. So that, to his mind, a perfect electrical governor ought to be capable of electrically controlling an engine without any appreciable loss of electrical current.

Mr. Edward B. Marten asked how much of the power of the electricity generated was absorbed in working the governing apparatus now exhibited.

Mr. David Greig remarked that electricity was progressing at such a rate that it was difficult to say to what position it might not ultimately attain.

In regard to the semi-portable engine he was sure it would be of interest if Mr. Richardson would state whether there was any difference in the consumption of steam, according as the cylinder was placed below the boiler or above. And with regard to the compound engine he wished to ask whether the cylinders were steam-jacketed; and if so, what advantage there was in putting the cylinders on the top of the boiler, so that the water from the jacket could drain back into the boiler, as compared with putting the cylinders below the boiler, where the water from the steam-jacket had to be raised and sent back into the boiler by force.

Mr. P. W. Willans observed that one advantage which had been claimed in the paper for electrical governors was that they would govern the engine when the driving belt slipped. But the only difficulty which he had experienced with electrical governors had been when the belt did slip. When that occurred the governor might go on putting on more and more steam. When a belt once began to slip it went on doing so, and it was eventually thrown off the driving pulley. His own governors had generally been put on for driving dynamos direct. Where governors were put on in connection with an engine driving dynamos by means of a belt, he thought it was important that there should be a mechanical governor for safety.

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With reference to the pull of the solenoid, it had been stated in the paper (page 386) that, with a solenoid having a pull of 25 lbs. for an electromotive force of 100 volts, a variation of about 4 lbs. was obtained with only 1 volt variation of electromotive force. That was a very large difference—a variation of 16 per cent. in the pull for a variation of only 1 per cent. in the current—the resistance of the solenoid being constant.

Mr. Nevile explained that the variation of 4 lbs. in the pull referred to the pull upon the valve, and not to the pull upon the solenoid. The arms of the lever being ten to one, the variation at the solenoid was only 0·4 lb., for a variation of 4 lbs. in the pull upon the valve.

Mr. P. W. Willans thought that it would be of interest if the author would mention the electrical power absorbed in the solenoid of his governor. In regard to the relay governors with which his own name had been connected, his object in using such governors had been to provide for the possibility of more power being required at one time than at another for working the regulating valve; because, although it was possible to pack a stuffing-box so that it should take very little power, yet in careless hands it might take a great deal of power. The stuffing-box friction had been left out of the calculation in the paper. Mr. Crompton had perhaps taken an extreme view in speaking of a ton as the force of pull required; but there were cases in which certainly a very great deal of power was required, as was shown by the size which experience had proved it to be necessary that the relays should be made. The governor which had been mentioned by Sir James Douglass as worked by a weight that was wound up was simply a relay governor, nothing more. A suggestion had been made that the governing might be effected by inserting more or less resistance in the field-magnet coils; and this had been suggested by Mr. Andrews in connection with his electrical governor, which he believed to have been the first electrical governor ever proposed. With the relay governor it was quite easy to insert this resistance; and his own aim all along had been that electrical governors

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(Mr. P. W. Willans.)
should not be confined to engines, but that they might be used for any purposes. Without a relay of power he thought it would not be easy to do any heavy work economically.

Referring to the two little cylinders shown in Figs. 1 and 2, Plate 50, acting upon opposite sides of the fulcrum of the compensating lever, he enquired whether these were intended to compensate for the pressure on the valve-spindle, or whether the valve was made with the facings so large that they required compensation. The valves that he himself used were piston-valves, admitting steam at the circumference, and therefore requiring no compensation; and even if they did require more power to move them in one direction than in the other, or more at one time than at another, the reserve provided in the relay cylinder was ample.

Sir James N. Douglass explained that in the suggestion which he had offered of governing by a falling weight he had not referred to any particular governor; and such a plan he thought could scarcely be classed as a relay governor. The kind of governor he had in mind was one in which the power would be provided either by a falling weight or by pressure of steam or by weight of water, and which would be provided with an escapement that would be released by the electric current. He had not seen such a governor; it was merely a suggestion which had occurred to himself in reference to the method adopted for the automatic governing of electric lamps that had been working thirty years with perfect success.

Mr. P. W. Willans thought the principle was the same as in the relay governor, both plans being in agreement with regard to the use of electricity as the means of regulation, and the introduction of some external power to do the actual work of moving the valve or the regulating mechanism.

Mr. L. Sterne wished to enter a slight protest against the reference made in page 380 of the paper to the "unpleasant bobbing" generally seen in electric lights driven by a gas engine where there were no accumulators. Gas engines were now made which had

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an ignition every revolution, and which certainly gave a very steady electric light; while on the other hand he had seen some very unsteady lighting with the use of steam engines. He was glad that Mr. Nevile had been led, by the difficulties which he had encountered with steam engines as the motive power for electric lighting, to devise some means whereby electric lighting could be rendered agreeable to the eye. If gas engines had been in use for as long a time as steam engines, he thought there would probably be more condemnation of the steam engine than there was at present of the gas engine. Gas engines manufactured lately by his firm were driving dynamos maintaining electric lighting with uniform steadiness whether sixty lamps were on or only ten, and without the aid of accumulators. All recent gas engines made by his firm were governed by an improved governor gear, making the engine run exceedingly steady; and the amount of gas used was in exact proportion to the work, which was done very economically.

Mr. Richardson said Mr. Greig knew quite as well as himself that it could make no difference whatever to the total consumption of steam whether the cylinder was placed above or below the boiler; nor could it make any difference in the consumption of steam in the steam-jacket. But he certainly admitted, with Mr. Greig, that when the cylinder was placed above the boiler, and the water from the steam-jacket drained back into the boiler, there was a slight gain; because, although there was no waste from the steam-jacket so long as the steam went back into the boiler, yet when the cylinder was below the boiler there was of course a small loss of power in pumping up the condensed water from the reservoir and forcing it back into the boiler. Mr. Greig knew also as well as himself—otherwise he would not have adopted the same plan in his own engines—that while there was no saving in steam there was a great gain in stability by placing the cylinder and the working parts upon a base-plate upon the ground-line.

In regard to the drop in the steam pressure, to which attention had been drawn by Mr. Halpin in connection with the indicator diagram, Plate 49, the drop of 15 lbs. from the boiler pressure of 120 lbs. to

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(Mr. Richardson.)

the initial pressure of 105 lbs. in the first cylinder was accounted for by the circumstance that the engine was one which had been made for pumping purposes only, and was fitted with a throttle-valve between the boiler and the high-pressure cylinder. The throttle-valve accounted for the loss of pressure. As there was no throttle-valve between the receiver and the low-pressure cylinder, there was no loss to account for there. In that engine both the cylinders were well jacketed, and were so arranged that their steam-jackets served as heaters for the steam receiver; and this accounted for the approximation being so close that no difference could be shown between the exhaust line of the high-pressure cylinder and the initial pressure in the low-pressure. With a separate cut-off valve for the low-pressure cylinder it would be found that the same initial pressure could be got in the low-pressure cylinder that was left off with in the high-pressure, giving an indicator diagram like that shown in Plate 49. The engine from which that indicator diagram was taken ran at a speed of 90 revolutions per minute.

With reference to the stuffing-box of the valve-spindle, he managed to get it so packed that the weight of the valve itself was quite sufficient to overcome the friction of the packing; and he had not found that anything like a pull of 30 or 40 lbs. was required to move the valve. Mr. Crompton's conclusion was quite correct that with the arrangement shown in the drawings there was very little for the solenoid to do; that was exactly what had been aimed at in designing the arrangement, namely to give the solenoid but little to do. In arc lighting there was no waste of current, because it was the main current that went round the solenoids, which were smaller than those used for incandescent lights; and no compensating arrangement whatever was needed, the simple lever and valve being quite sufficient to make the variation in speed that was necessary in arc lighting. The engine speed could vary from 15 revolutions per minute to 140 without the light fluctuating. In the compensating arrangement here shown for incandescent lighting there were three things to be compensated. One was the varying pressure in the boiler; of course the boiler pressure should not vary, but

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practically it did, especially with a bad man. Then there was the varying pressure in the steam-chest, due to the difference of load. And thirdly there was also the varying pressure of the electromotive force. Each of the two little cylinders acting upon the compensating lever had therefore something to do. One of them compensated perfectly for the varying pressure in the boiler, and the other for the varying pressure in the steam-chest, thus leaving very little for the solenoid to do; but what little it had to do it did perfectly, and maintained the electromotive force uniform.

Mr. NEVILE admitted that the idea of controlling the electromotive force from a distance was not a novelty to electrical engineers; and he had merely mentioned it in the paper in reference to the method adopted in his own case, and to show how that method might be applied on a larger scale.

He explained that the maximum differential pull of 6 lbs. shown in the diagram Fig. 11, and of 3 lbs. in Fig. 12, Plate 54, was the pull upon the valve, not upon the solenoid. The valve was actuated by the solenoid through a lever with a ratio of ten to one, so that the highest variation of 6 lbs., shown in the diagram Fig. 11, became when transferred to the solenoid a variation of only 0·6 lb.; and a variation of 1 volt in the electromotive force produced a difference of 0·4 lb. in the pull of the solenoid, which would be transferred to the valve as a variation of 4 lbs. in the pull on the valve-spindle. Even in the extreme case of the valve requiring 30 lbs. to move it, this would be obtained by a difference in electromotive force of only about 7 per cent. Practically the friction of the packing in the stuffing-box of the valve here shown did not require he believed so much as 1 lb. pull to move the valve, for when there was no steam pressure the valve would always drop by its own weight, which amounted to only about 11 ounces. It was true that a mistake might be made of screwing up the stuffing-box too tight; but even if there were no stuffing-box, things might still happen to go wrong. In the Willans relay governor, for instance, the water supply might possibly fail, which he was afraid would cause an

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(Mr. Nevile.)
accident of some description; and it might perhaps fail in a more sudden manner than would arise from merely screwing up a stuffing-box too tight.

With regard to the question asked by Mr. Timmis as to the electromotive force of this governor, the same electromotive force was required that there was in the circuit, and the quantity of current used was 1·8 ampère. The governor exhibited was made for a 16 HP. engine, which would drive 300 lamps of 20-candle power, each lamp using at 100 volts about 0·65 ampère; that would be 195 ampères total current generated, of which the governor would take 1·8 ampère, or less than 1 per cent. It might be made to work with a rather less current he believed, but that was the amount of current now taken with the wires actually used; a governor for a smaller engine could be made to take less than 1 ampère of current. The perfect am-meter foreshadowed by Mr. Timmis was one which he should certainly be glad to see. As to the use of accumulators, he did not look with great favour upon the idea of having an engine running all day and night; he should not be satisfied to leave an engine running for nine hours at night by itself—at least none that he had seen. Of course if that were to be the case, engine-drivers would scarcely be wanted.

The objection urged by Mr. Crompton to this arrangement of governor, that there was a great deal more than the solenoid could do, seemed not quite compatible with his subsequent remark that if the two compensating pistons did their work properly there would be very little for the solenoid to do. The latter was the nearer to the true representation. Mr. Crompton had also remarked that the Willans governor was no larger and had no more parts in it than the governor now shown with the compensating arrangement. This might be true, although he certainly thought the present governor was simpler to make; but there was one essential difference, namely that, if the compensating arrangement for perfect regulation were to fall out of action, it would still leave the main electrical governor in action, which would not allow any large variation; whereas if the hydraulic part of the other governor were to fail from want of water or any other cause, the electrical part would entirely lose control,

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and the throttle-valve would either fly full open or close entirely. A governor of this description could of course be made to regulate by altering the resistances in a field-magnet circuit, as well as a relay governor did. Although he had not yet tried the plan, it could certainly be done in his own case; and he thought he saw several ways of doing it.

With reference to the remarks of Sir James Douglass about arc lighting, the paper had dealt only with house lighting; and arc lighting was of course impracticable for a small house, because it could not be carried out in small rooms.

It appeared to Mr. Walker that the same result of keeping the electromotive force constant at the house might have been obtained by increasing the leads to the house, instead of connecting on the governor at the house. To do this however, and to keep the electromotive force at the house within 2 volts of what it was at the engine room when 60 ampères were passing, would have necessitated the mains being of six times the weight they now were; and as they now weighed about 194 lbs., being 360 yards long, this would have meant an increase of 970 lbs. of copper; whereas the only increase of copper involved in the present method was 360 yards of No. 16 copper wire of about 14 lbs. weight. Of course the use of the larger mains would have given some decrease in the amount of power lost in them, and so some slight saving in coal; but not sufficient he thought to compensate for the increased prime cost of the 970 lbs. of copper wire.

It had also been remarked by Mr. Walker that no mechanical governor would give a rising speed to a rising load. But if speed only were in question, a mechanical governor fitted with the compensating arrangement described in the paper could do this; it was only a question of what might be called over-adjusting the cylinder in connection with the steam-chest, so that, as the pressure in the steam-chest rose, the relieving pressure on the lever should rise to a greater extent than would keep the speed uniform, and so should cause it to increase.

Great things had been predicted by Mr. Walker for compound dynamos; but at their best it appeared to him that they still retained

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(Mr. Nevile.)
the two main imperfections to which he had alluded in page 382,—namely that their use was limited to the particular circuit and particular electromotive force for which they were severally wound, and that they were awkward for working in conjunction with secondary batteries.

As to the objection of Mr. Willans to the governor taking up the slipping of the driving belt, he thought that belts always slipped more or less, and always varied more or less in the amount of their slipping; he did not believe that any belt could be got which would really transmit the speed exactly the same as that of the engine. There would always be some slight slip, and he thought it was an advantage when this was taken up by the governor. The driver ought of course to be able to see if the belt was slipping so much as to be seriously dangerous; and then he must stop the engine and tighten it up.

The compensation required in the working of the governor was owing to the difference of area of the two flanges of the double-beat throttle-valve. The aperture in the upper seat was just large enough to allow the lower flange to pass through it with an easy clearance; and owing to the upper flange being therefore larger than the lower, there was always an effective pressure upwards, which increased as the steam pressure rose. There was also an upward pressure upon the valve-spindle, which varied in amount with the fluctuations of pressure in the steam-chest. The double-beat valve had been used in preference to a piston-valve, because it was thought a good deal less likely to stick than a piston-valve.

In regard to the gas engine, he had used the word "generally" and not "always" in referring on page 380 to the unpleasant bobbing generally seen in electric lights driven by a gas engine where there were no accumulators; and he thought that generally the lights did bob under such circumstances. Certainly he had not yet seen a gas engine that he was satisfied with for electric lighting; for when the engine was fully loaded and there was an ignition at every revolution, it was then only half as good as a steam engine, because there was only one impulse in every revolution, whereas a single-cylinder steam-engine had two. The difficulty was greatest when there was

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a light load. In his own house, where the maximum number of lamps required at any one time was fifty, the lighting started with perhaps twenty or thirty, and got up gradually to fifty in the course of the evening; while later on there were only perhaps five or six lamps in the billiard room, and scarcely another alight in the house. Now when there was a gas engine that was made to drive up to fifty lamps, taking then an ignition at every revolution, it would only take an ignition at every three or four revolutions when driving only five or six lamps; and it therefore seemed to him that bobbing must then take place. There were methods in progress he had heard for regulating the gas admission in the same way as the admission of steam, so that the gas engine should receive an impulse in every revolution, whether it was doing much work or little; but he had not yet seen one on that principle.

The Rev. Precentor VENABLES thought there might be a very happy practical outcome from the visit of the Institution to Lincoln, in connection with the special service in the Cathedral on the previous evening, when the members who were present must have realised the difficulty the Dean and Chapter and authorities of the cathedral were under in accommodating such a large gathering, in consequence of the very limited space contained within the portion of the cathedral that was set apart for the usual services. Probably therefore one of the first objects to which the authorities would direct their attention would be the proper lighting of the nave of the cathedral. He would accordingly suggest what a very happy and valuable practical result it would be of this meeting of Mechanical Engineers in Lincoln, if, by the advice of those who were qualified to give it, the Dean and Chapter should be put in a position to make Lincoln Cathedral the first cathedral in the country which was illuminated by the electric light. Messrs. Robey's works had for some time been illuminated in that way; and it was well known how perfectly practical and useful the plan had been found in such cases, and also how very economical, as Sir James Douglass had stated, the arc light was in large buildings. Hence they would be thankful and proud if their cathedral in Lincoln were illuminated with the

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(Rev. Precentor Venables.)

electric light, which no doubt would be the light of the future. It had to work its way against many difficulties, many mistakes, and even a great deal of ridicule. But those who had read Lord Campbell's life would remember the ridicule and utter scorn with which he spoke of the absurd idea of laying on an illuminating fluid to houses, just as water was laid on; and yet that which had come to pass with regard to gas would no doubt come to pass with regard to the electric light. The Church indeed desired to welcome all science, knowing that scientific truth, as well as the religious truth with which she had specially to deal, were both alike revelations of the same Divine Being. Certainly the cathedrals, as the foremost religious edifices in the country, should be the first to welcome every fresh development of science; and he should regard it as a proud event for the Dean and Chapter of Lincoln if their minster was the first to welcome the electric light within its sacred walls.

The President thought that, after the announcement which had just been made by the Precentor, the Dean and Chapter of Lincoln Cathedral might expect a good many visits from electrical engineers in the course of the next few days.

He had now great pleasure in moving a vote of thanks to Mr. Richardson and to Mr. Nevile for their very acceptable papers, which had given rise to so interesting and profitable a discussion.

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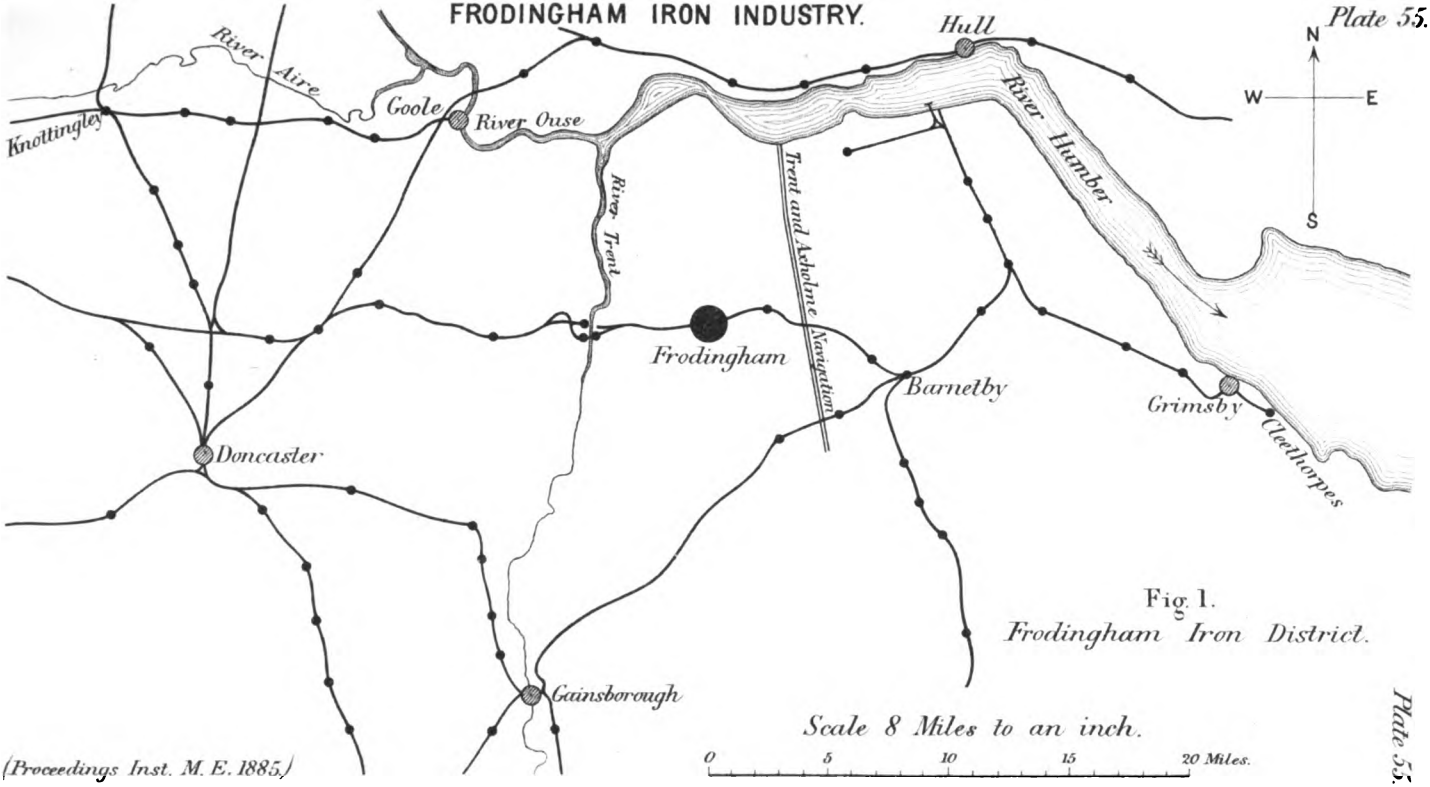

Fig. 1.
Frodingham Iron District.

(Proceedings Inst. M. E. 1885.)

Plate 55.

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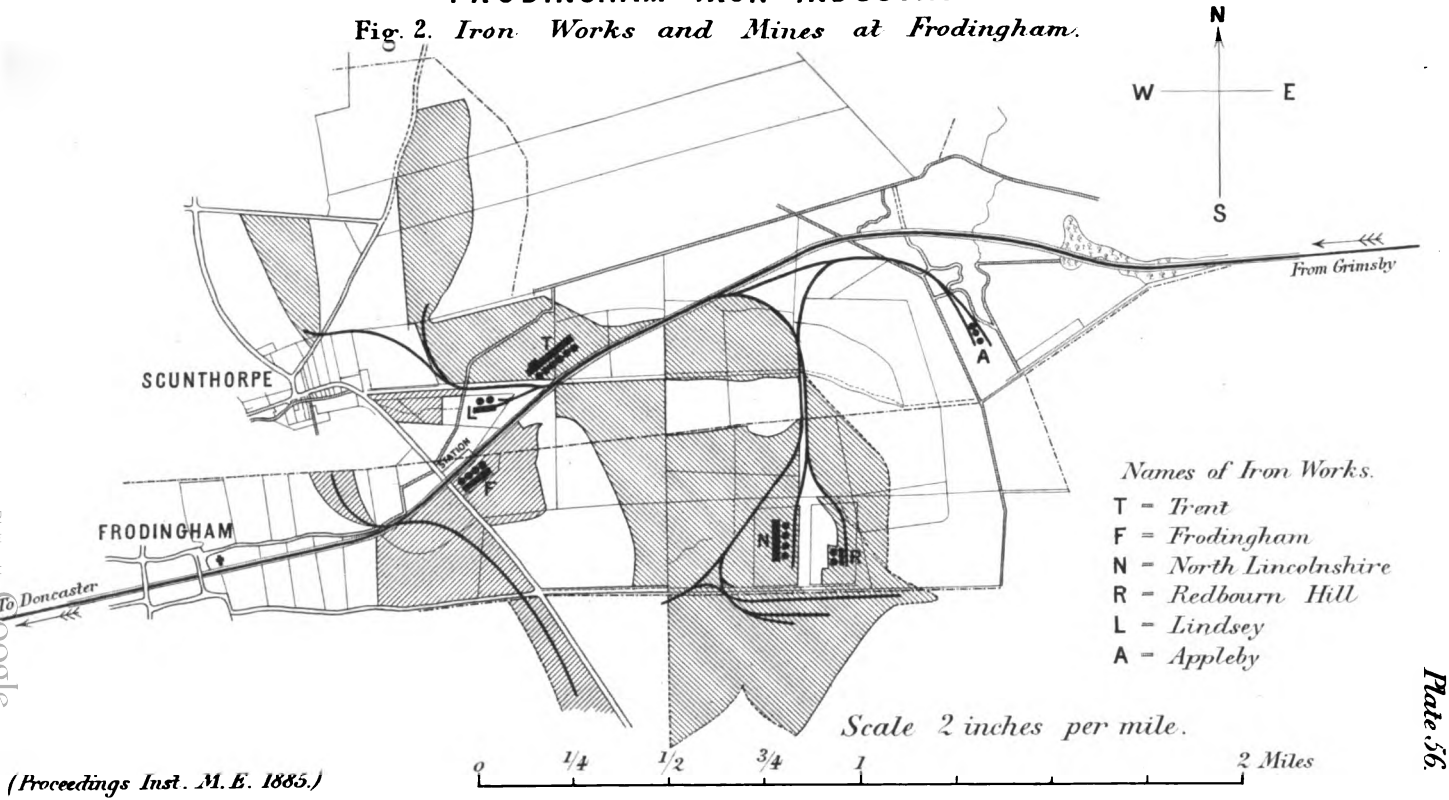
FRODINGHAM IRON INDUSTRY.

Fig. 2. *Iron Works and Mines at Frodingham.*



(Proceedings Inst. M.E. 1885.)

Plate 56.

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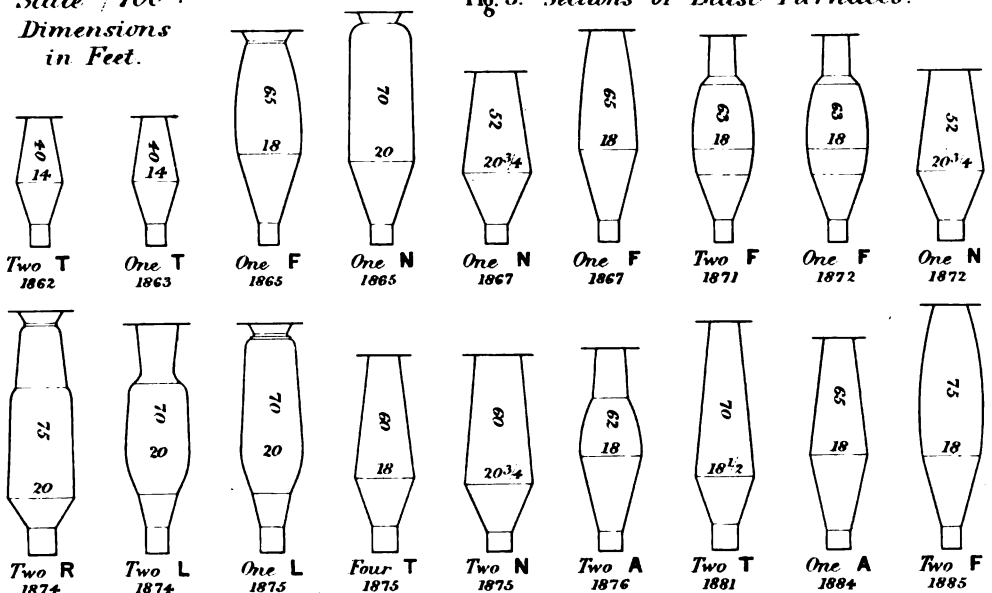
FRODINGHAM IRON INDUSTRY.

Fig. 3. *Sections of Blast Furnaces.*

Scale 1/700th
Dimensions in Feet.



Names of Iron Works.

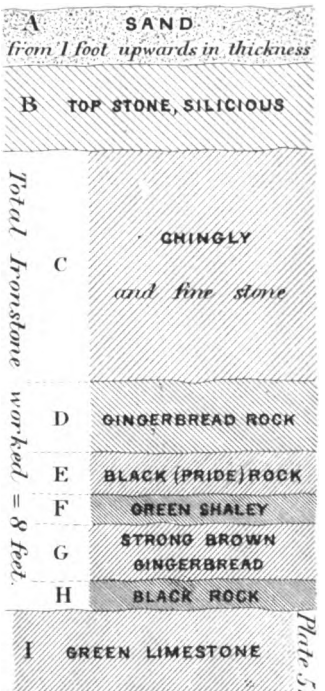
Dimensions in Feet.

(Proceedings Inst. M. E. 1885.)

T = *Trent.* F = *Frodingham.* N = *North Lincolnshire.*
R = *Redbourn Hill.* L = *Lindsey.* A = *Appleby.*

Plate 57.

Fig. 4. *Section of Strata.*
Scale 1/40th



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ON THE IRON INDUSTRY OF FRODINGHAM.

By Mr. GEORGE DOVE, of Frodingham.

The writer has been requested to compile a few facts and figures bearing upon the present position of the Iron Industry of North Lincolnshire, in view of the excursion to Frodingham which is arranged for the concluding day of the present week's meeting. A former paper prepared by him with a similar object for the Iron and Steel Institute in 1876 (Journal, page 318) brought the history of the district down to that year. Since then the total number of blast furnaces has not been increased, the list being now as follows:—

Name of Works.	In blast.	Out of blast.	Total.
Trent Iron Works	4	2	6
Frodingham Iron Works . .	2	2	4
North Lincolnshire Iron Works .	2	2	4
Redbourn Hill Iron Works . .	2	2	4
Appleby Iron Works . . .	3	0	3
	13	8	21

The plan shown in Fig. 1, Plate 55, indicates the connection of the Frodingham district with the railway system; and that in Fig. 2, Plate 56, shows the position of the several works and mines. In Fig. 3, Plate 57, are shown the sections of the various furnaces. These are mainly of the Cleveland type, with the difference that all, excepting two of those of the Redbourn Hill Co., are open-topped. The stone being charged in "raw," as it comes from the mines, it is probable that any more furnaces which may be built will also be of the open-topped class. The tendency as regards size appears to be in the direction of increase in height.

The sections of furnaces in Fig. 3, Plate 57, are arranged in order of date, beginning with the two Trent furnaces T, erected in

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1862, of 40 feet height and 14 feet diameter across the tops of the boshes. Since that time the heights have ranged up to 75 feet, and the diameters up to 20¾ feet. The two furnaces lettered L in the lower row, originally erected by the Lincolnshire Smelting Co., now belong to the Redbourn Hill Co., and are at present out of blast. The latest furnaces are the two F at the Frodingham Works, altered in the present year to 75 feet height, the diameter being 18 feet.

The hot-blast stoves in use are of the ordinary cast-iron pattern. In one instance only, that of the Frodingham Iron Works, have fire-brick stoves been built; but of the results of their working the writer has no information.

The bed of ironstone dips gently to the east, the covering being sand, which is about one foot in thickness at the outcrop, increasing to upwards of twenty feet at the lowest part of the workings. The operation of getting the stone is simply one of quarrying, and very little blasting is required. The removal of the sand is mainly accomplished by manual labour, though the cranes made by Messrs. Priestman Brothers of Hull are being employed with satisfactory results.

An examination of the face of stone shows it to consist of strata varying in mechanical condition and chemical character. The following is a fair example of the thicknesses of the several strata in the bed, as shown in Fig. 4, Plate 57 :—

		Ft.	Ins.	Ft.	Ins.
A	Sand, from 1 foot upwards in thickness				
B	Top stone, silicious			1	6
C	"Chingly" and fine stone	4	0		
D	"Gingerbread" rock	1	3		
E	Black (pride) rock	0	9		
F	Green shaley	0	6		
G	Strong brown "gingerbread"	1	0		
H	Black rock	0	6		
	Total Ironstone worked			**8**	**0**
I	Green limestone			1	6
	Total thickness of bed			11	0

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The annexed Table of analyses (page 417) may be taken as fairly representing the composition of the bed. From this it will be readily understood that great care is required in selecting the stone, in order to obtain the best results in the blast furnace. With careful selection it can be smelted alone, without any admixture of other stone; but in practice it is found desirable to use a portion of Northamptonshire or other silicious ore, which assists in the working of the furnace and acts as a safeguard against any accidental excess of lime in the charge.

The following are analyses of samples of the iron made:—

	No. 1.	Grey Forge.	White.
Iron	90·280	91·990	94·220
Combined Carbon	0·585	0·348	2·300
Graphitic Carbon	3·767	2·264	0·690
Phosphorus	0·965	1·119	1·170
Sulphur	0·006	0·019	0·102
Silicon	2·710	2·291	0·629
Manganese	2·255	1·799	0·888

The bulk of the make is "forge" iron; but there is an increasing demand for better qualities of "foundry" iron, for use as mixtures with other irons.

Considerable development has taken place during the past ten years in the working of the Frodingham ironstone for consumption in other districts, where its calcareous character adapts it for use as a mixture with more silicious ores. During the year 1884, 293,052 tons of stone were sent out from Frodingham; and the quantity consumed in the local furnaces having been 848,249 tons, the total quantity raised during the year was 1,141,301 tons. This represents in round numbers 326,086 tons of iron made from Frodingham ironstone in 1884.

The fuel used in the furnaces is entirely coke, which is obtained from Durham and South Yorkshire. The latter is the natural field from which all the supplies should be obtained; and that more attention is being paid to the manufacture is shown by the marked

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increase in the output, which in 1884 was 412,000 tons as against 291,000 tons in 1880. But the quality of the material manufactured in this nearer district is generally so inferior that the ironmakers are of necessity compelled to draw a portion of their consumption from the more distant coalfield. It is demonstrated that it is possible from the Barnsley bed of coal to make a coke equal in chemical composition to the average Durham brands, though perhaps wanting somewhat of their splendid mechanical condition. But the fact remains that the bulk of the coke manufactured in South Yorkshire is at present of a very inferior description; and until a material improvement is effected, the Durham coke will continue to be introduced into what should be the natural outlet for South Yorkshire coke. In his former paper the writer ventured to point out two factors which would materially influence the future of the Frodingham ironfield:—namely, the proper selection of the stone, and the fuel supply. The selection of the stone may be said now to be practically carried out; and there remains but a much needed improvement in the quality of the fuel from the adjacent coalfield. During the long continued depression in the iron trade, Lincolnshire may be said to have fairly held its own; but with the second condition fulfilled, it will have a great future.

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Analyses of a section of Ironstone Bed in the Frodingham Mines.

Stratum in Bed. *See page* 414, *and Fig.* 4, *Plate* 57.	B	C	D	E	F	G	H	I	Average of worked beds C-H
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Peroxide of iron	23·290	41·170	32·430	44·350	20·240	46·720	35·841	18·970	39·527
Protoxide of iron	trace	trace	nil	nil	23·440	nil	nil	9·024	1·465
Silica	45·637	5·070	3·099	5·920	7·811	8·101	3·409	2·212	5·383
Lime	1·710	14·450	24·102	13·550	5·801	8·380	20·071	34·420	14·589
Manganous Oxide.....	0·689	1·379	2·347	2·500	2·523	3·501	5·870	1·513	2·258
Sulphuric Acid.....	0·036	trace	0·002	trace	0·370	0·103	trace	2·096	0·036
Phosphoric Acid	0·256	0·678	0·991	0·547	0·687	2·680	0·603	2·291	0·947
Alumina.....	4·755	0·711	2·904	2·569	4·115	1·753	2·763	1·006	1·689
Carbonic Acid	nil	12·890	15·145	6·065	16·800	4·570	14·500	21·710	11·624
Magnesia	0·411	0·375	0·191	0·463	2·520	0·205	trace	0·440	0·475
Alkalies	0·472	0·296	0·458	0·490	0·610	0·842	0·530	0·532	0·443
Organic matter.....	0·169	trace	—	—	—	—	—	—	—
Water at 212° F.	16·179	17·572	12·824	15·124	9·254	13·874	11·750	4·088	15·327
Water combined	6·571	5·303	5·166	8·216	5·846	9·150	4·715	1·512	6·128
Total.....	100·175	99·894	99·659	99·792	100·017	99·878	100·050	99·814	99·889
Total insoluble matter	46·052	5·521	3·434	6·651	9·163	8·775	4·162	3·038	5·953
Loss on calcination ...	22·919	35·765	33·135	29·505	30·900	27·594	30·965	27·300	33·028
Iron in dry stone	21·10	37·56	26·79	38·31	36·97	41·80	29·22	21·41	36·029
Iron in wet stone	16·30	28·82	22·79	31·04	32·40	32·76	25·08	20·30	28·815

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Discussion.

Mr. CHARLES COCHRANE considered the members were very much indebted to the author for supplying by this descriptive paper the means of understanding more readily what they would see in the excursion to Frodingham. In reference to the capacity of the blast-furnaces, and the gradual development which had taken place from the very small and almost insignificant furnaces of 40 feet height and 14 feet diameter up to 75 feet height and 20¾ feet diameter, it was evident that Lincolnshire had found the importance of largely increasing the size of the furnaces. But what had surprised him was that the charging bell had not been more generally adopted for taking off the gases and economising fuel at the boilers and at the stoves; and he hoped the author would give some explanation as to why the bell had not been adopted, with such an important economy in store for those who did adopt it. Was the progress of the district in that respect interfered with in consequence of the large quantity of moisture, which the iron ore contained, preventing the gas from being used with efficiency? It was remarkable that only at one furnace was the author able to record the application of the highly superheated blast obtained from fire-brick stoves; he did not know whether it had been attended with any disappointing results in the one case in which it had been applied; but if so he should be glad to be informed of the circumstances.

With reference to the quantity of coke consumed per ton of iron in the best furnaces in the district, he enquired whether this had been brought down to anything like 19 or 20 cwts. of coke per ton of iron: so as to get some idea of what improvement the furnaces were still capable of. If they still used from 22 to 25 cwts. of coke, no matter whether it came from Yorkshire or from Durham, there was still an improvement in store, unless it were limited by the size of the stone itself. In that respect he was pleased to see that the furnaces had been able to reach such a height as 75 feet. When on a visit to Lincolnshire many years ago he remembered that the smallness of the stone, coupled perhaps with the accident of bad

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selection from the bed itself, was such as to prevent the blast from passing up freely through the furnace; and so the furnaces were debarred at that time from improvements which he hoped were now rendered possible by the better selection of the stone, in recognition of the fact that it must be selected in order to get the best results in the blast-furnaces.

Mr. Dove replied in regard to the charging bell that the first large blast-furnace built in Lincolnshire was erected by Mr. Adamson in 1865, 70 feet high and 20 feet diameter, and closed with a bell. After it had been working some little time under disadvantageous circumstances so far as the supply of ironstone was concerned, there was an unfortunate accident, and one half of the furnace was blown off. For some years afterwards, till 1872 or 1873, bells were not used in Lincolnshire at all. In 1874 at the Redbourn Hill Works two furnaces were built which were fitted with bells; and these two furnaces had been working with the bells ever since, with fairly satisfactory results. As to the question of coke consumption per ton of iron, he did not now think, though for years he had been of a different opinion, that there was any saving in the working of furnaces fitted with bells. The manufacture of iron could be carried on in open-topped furnaces with as low a consumption of fuel as in those fitted with the bell top. Moreover with a sufficient chimney draught there was no difficulty in drawing off gas enough from the open-topped furnaces for the stoves and boilers. In some of the open-topped furnaces a cylinder was fixed in the throat, of the full diameter of the throat and hanging down into the furnace to a depth of 6 to 10 feet, which materially assisted the chimney in drawing off the gas from the closed annular chamber so formed around the cylinder; but with a sufficient chimney draught there was no difficulty in drawing off gas enough from open-topped furnaces without any such cylinder in the throat. In Lincolnshire there were no coals used under any of the stoves or boilers. In favour of the open-topped furnaces there was of course the fact that the ironstone contained a large percentage of moisture, running up sometimes to 25 and even 30 per cent. in weight. With the bell the

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(Mr. Dove.)
whole of that heavy percentage of moisture would be drawn off in the gas, and would pass under the stoves and boilers, which considerably militated against the heating efficiency of the gas. Besides this, there was the secondary advantage of the open-topped furnace, that its working was open to view. For with every attention to the working and every care in the selection of the ironstone, there sometimes occurred some little trouble from excess of lime, which occasionally led to scaffolding. This did not now happen so frequently as in former years; but some disorganisation had occurred now and then.

With respect to the coke employed, he regarded it as a matter of the utmost importance to North Lincolnshire that the whole of it should come from the South Yorkshire coalfield. There was no question but that in the course of time it would do so. Lincolnshire had passed in its early years through similar experience to that which Cleveland had gone through in starting. Whilst the Cleveland furnaces had an admirable ironstone, their success had been to a very great extent due to the quality of the fuel which could be obtained from the adjacent Durham coalfield; and he hoped that at some time or other the Lincolnshire furnaces would be able to obtain their entire supplies from their adjacent coalfield, of a quality equal to that of the north; and until this was so, Lincolnshire was not obtaining the full advantage of its geographical position. The consumption of coke per ton of iron varied considerably at the different furnaces; and the conditions under which they were working—some working with all South Yorkshire coke, and some with different proportions of Yorkshire and Durham—rendered the results so different that he was unable to give any figures which might be taken to represent an average of the consumption of fuel per ton of iron in the district.

The PRESIDENT mentioned that he had received a letter from Mr. Adamson—who had been referred to as having built the first large close-topped furnace at Frodingham, and who continued to take a great interest in the subject of this paper—expressing his regret that he was not able to be present.

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As the paper was largely of a geographical and descriptive nature, much discussion upon it could scarcely be expected. It had been prepared in order to give additional interest to the excursion to Frodingham; and he was sure they were all very much obliged to the author for laying before them so clearly as he had done these interesting particulars, in the absence of which their visit to the district would have been somewhat bare and far less intelligible. He proposed that their best thanks be given to Mr. Dove for his paper.

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DESCRIPTION OF THE TRIPIER SPHERICAL ECCENTRIC.

By M. LOUIS POILLON, of Paris.

The object of the Spherical Eccentric, the invention of M. Victor Tripier, is to reverse by means of a single movable eccentric, which will also give all grades of expansion between full forward and full backward gear; and thus to realise the same results that are usually obtained only by the use of a link-motion having two separate eccentrics set with a fixed lead forwards and backwards.

As seen in Figs. 1 and 2, Plate 58, the spherical eccentric E has a rectangular slot cut through it, allowing it to slide transversely upon a flattened portion of the driving shaft D, while carried round by the rotation of the shaft, to which it is attached by a centre pin C passing through the shaft and through projecting eyes upon one side of the eccentric. The rim of the eccentric, instead of being cylindrical as usual, is shaped spherical, forming part of a sphere whose centre is midway in the thickness of the eccentric. A sleeve S, sliding lengthways upon the shaft, and adjustable longitudinally by means of a screwed collar J working in a stationary nut, is connected with the eccentric by a pin joint A, on the same side of the eccentric as the centre pin C. The pin joint A and the centre of the sphere thus form the two extremities of a bell-crank lever centred at C, as seen in Fig. 1; and by means of a hand-wheel or lever L on the screwed collar upon the sleeve S the centre of the spherical eccentric can be shifted from full forward gear F to full backward gear B, or to any position intermediate between these two extremes. On the pedestal P, carrying the stationary nut at the end of the shaft, is cast also a guide G for the snug H upon the eccentric-strap to work in.

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Fig. 1.

Longitudinal Section.

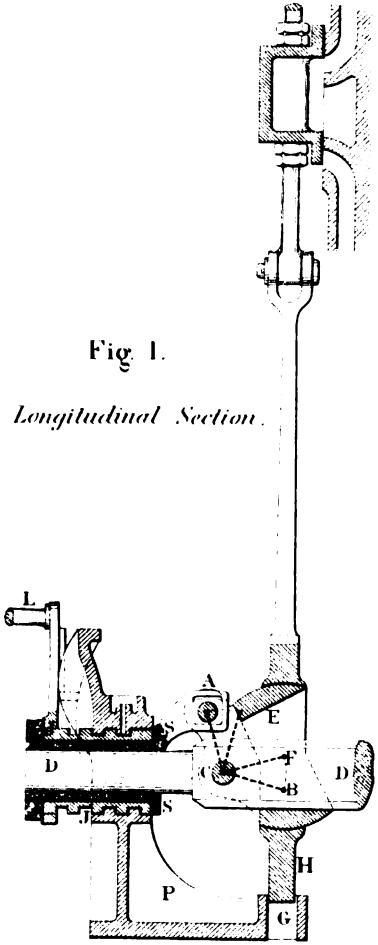


Fig 2.

Back Elevation.

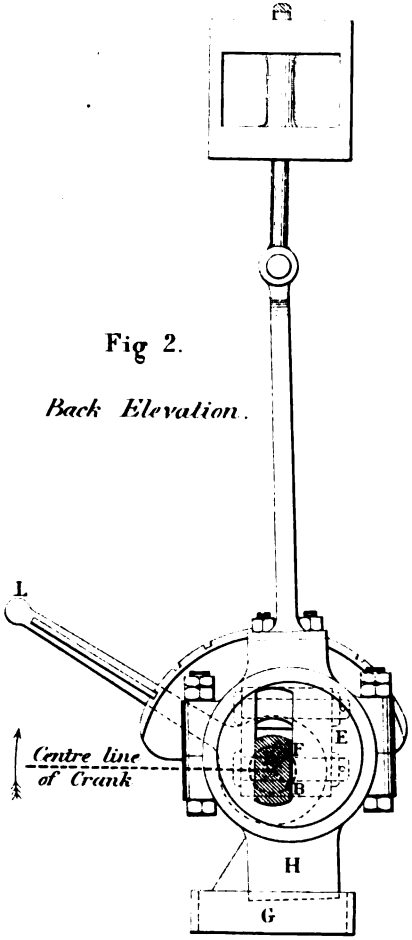
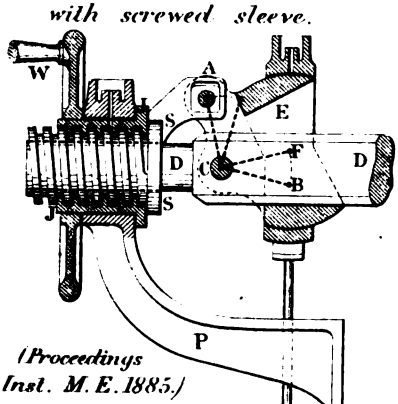
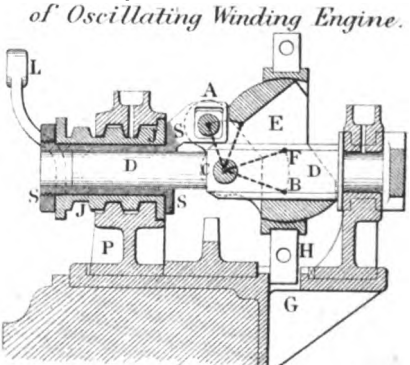


Fig. 3. *Eccentric with screwed sleeve.*



(Proceedings Inst. M. E. 1885.)

Fig. 4. *Eccentric of Oscillating Winding Engine.*



Scale 1/20th

Ins. 12 6 0 1 2 3 4 Feet

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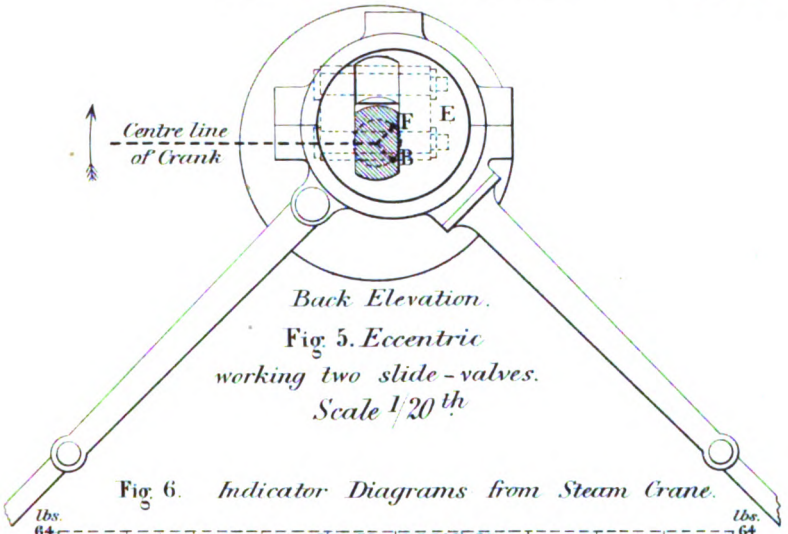


Back Elevation.

Fig. 5. *Eccentric working two slide-valves. Scale 1/20th*

Fig. 6. *Indicator Diagrams from Steam Crane.*

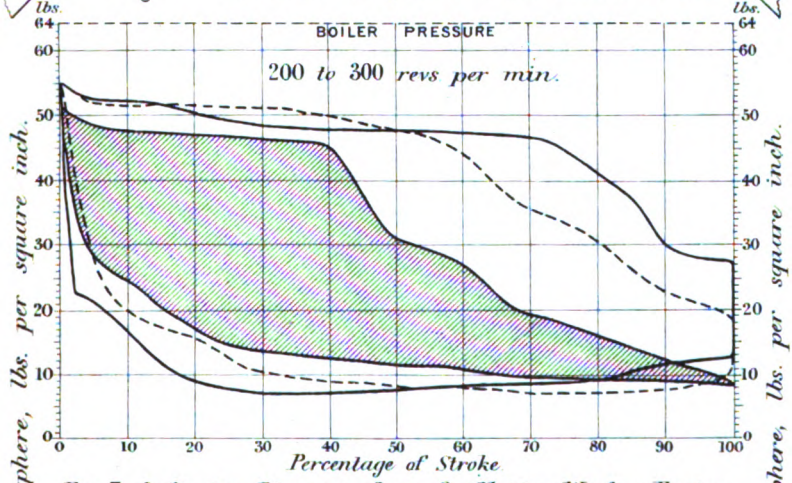
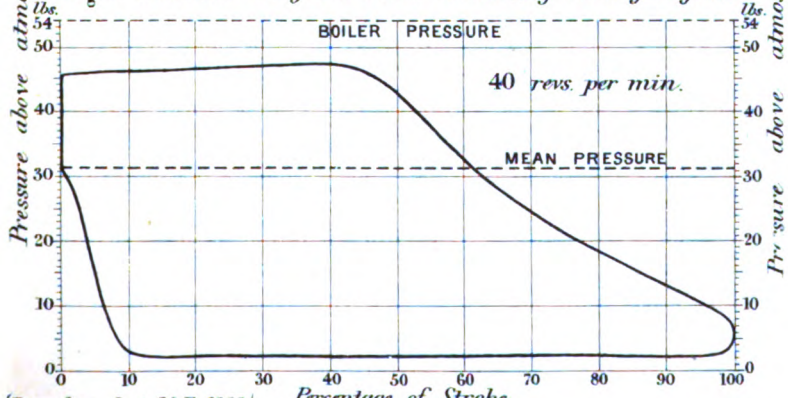


Fig. 7. *Indicator Diagram from Oscillating Winding Engine.*



(Proceedings Inst. M.E. 1885.)

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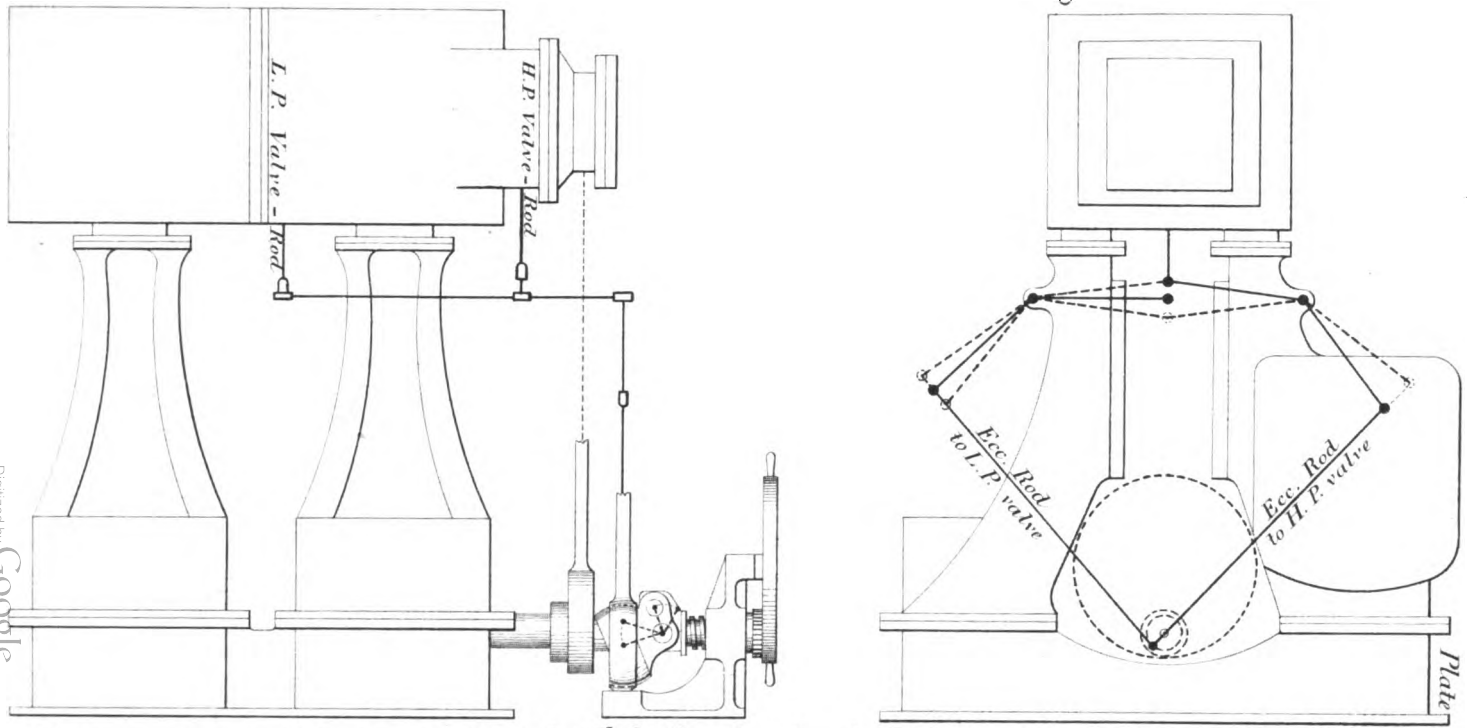
SPHERICAL ECCENTRIC.

Plate 60.

Fig. 8. *Side Elevation.*

Application to Marine Engines.

Fig. 9. *End Elevation.*



(Proceedings Inst. M.E. 1885.)

Scale 1/40th

Plate 60.

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From Fig. 2 it is seen that, in consequence of the slot through the eccentric being made straight, the throw is reduced from a maximum in full forward and backward gear to a minimum in mid gear. In the latter position, the centre of the eccentric coincides with a backward prolongation of the crank, and the throw is reduced to only double the lead,* while the compression is increased to such an extent as to prevent the engine from running either way. In either extreme position of the eccentric the distribution of steam is the same as if the slide-valve were actuated by a fixed eccentric keyed upon the shaft at the proper angle for full forward or full backward gear, the connection with the valve being made in the ordinary way, as shown in Figs. 1 and 2. In intermediate positions the distribution corresponds with what would be given by a fixed eccentric of diminished throw but with equal lead of the slide-valve.

With a single eccentric accordingly the same degree of perfection in the distribution is here obtained as by Gooch's link-motion with stationary link. That motion is not applied to marine engines on account of the room it takes up longitudinally. The spherical eccentric, on the other hand, lends itself readily to the requirements of marine-engine construction, as shown in Figs. 8 and 9, Plate 60; and in its simple form it gives as good a distribution of steam as in stationary engines and locomotives. In large engines the force required to shift the eccentric at starting can be given by a steam piston connected with the reversing hand-wheel.

For all engines that have to run both ways, forwards and backwards—such as locomotive and marine engines, steam cranes and winches, sugar mills &c.—the spherical eccentric affords a ready means of reversing. It is especially suitable for high-speed engines, such as those in torpedo-boats and steam-launches, inasmuch as its working, being that of only a single eccentric, is free from all risk of wear and tear, such as attends the ordinary link-motion. In

* By the word "lead" is here meant that of the eccentric, not that of the slide-valve. As pointed out in the discussion, "linear advance" would be the correct expression, the linear advance of the eccentric being equal to the sum of the lap and lead of the valve.

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engines with several cylinders, all the slide-valves can be worked from a single eccentric, as shown in Fig. 5, Plate 59, by taking off the motions from it through suitable connections.

If, instead of making the sleeve S, Fig. 1, to revolve and slide within the screwed collar by which it is adjusted longitudinally, the sleeve itself be screwed externally with a suitable thread, as shown in Fig. 3, Plate 58, and if the stationary nut in which it works be rotated by an independent motion at the same speed as the main shaft and in the same direction, the centre of the eccentric will not be shifted, and the distribution will continue the same. Conversely, by rotating the stationary nut at any speed in either direction, the engine will be compelled to run at the same speed and in the same direction, and will thus be controlled by the nut. This arrangement, with a hand-wheel W for rotating the nut, is suitable for any machines that are wanted to be controlled by hand while driven by steam, such as winches for discharging cinders, steam windlasses, hoists &c.

Similarly if the nut in which the screwed sleeve works be driven at a uniform speed by a turbine or other independent motion, the engine is thereby kept to a constant speed through the steam distribution, which is thus regulated for fluctuations of load, the consumption of steam varying with the work done. Applied on board ship and driven in a rough sea by any auxiliary engine available, it would prevent the main engines from running away whenever the screw comes out of the water, and would keep them working steadily at their normal speed.

The foregoing several applications of the spherical eccentric involve the use of only a single slide-valve; and the distribution is consequently attended with the same imperfections as in the case of the link-motion, namely an excessive compression when the steam is cut off early in the stroke. With a second cut-off slide mounted on the back of the main slide-valve, and worked by a second spherical eccentric, as high a degree of expansion as in the Meyer expansion gear can be obtained, with the advantage that the cut-off is sharper.

The use of the spherical eccentric, as will be gathered from the description already given, is attended with several advantages. The

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gear is easily erected, and without risk of errors in its adjustment. The cost is considerably less than that of ordinary expansion gear, and the wear and tear is insignificant; the wear occurs only between the rim of the eccentric itself and the eccentric strap, and on the collars of the sleeve; the former is easily taken up by tightening the strap, and the latter by tightening one of the collars that is loose on the sleeve. The two pins—namely that centering the eccentric upon the shaft, and that connecting it with the sleeve—are not exposed to wear, as they do not form working joints, but are stationary so long as the distribution continues the same; and the pressure upon them does not alternate, but continues on the same side during the working of the engine either in forward or in backward gear, and only changes to the other side of each when the engine is reversed.

At the Haveluy pit of the Anzin Collieries in the north of France the spherical eccentric has now been at work since March 1884 on a steam-crane of 5 or 6 HP. working night and day at a speed of 200 to 300 revolutions per minute. There have been no signs of wear, nor has it got out of order in any way; the first cost was 45 per cent. less than that of the Stephenson link-motion which it replaced. It has been found decidedly superior to the link-motion for the high speed of running, having the advantages of fewer joints, with the use of only a single eccentric, while both the lubrication and the wear are reduced to a minimum. In Fig. 6, Plate 59, are shown indicator diagrams taken from this engine, in regard to which however it must be noticed that the heavy back-pressure is here due to the exhaust-pipe being too small, in consequence of its being used as a blast-pipe.

At the same collieries the spherical eccentric has since been applied as shown in Fig. 4, Plate 58, to a winding engine with oscillating cylinders of 20 inches diameter and $7\frac{1}{4}$ feet stroke, from which the indicator diagram shown in Fig. 7, Plate 59, has been taken at a piston-speed of 580 feet per minute when cutting off at 45 per cent. of the stroke; the boiler pressure being 54 lbs., the mean pressure of the diagram is 31 lbs. per square inch.

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The spherical eccentric has also been applied to steam windlasses by Messrs. Mailliet of Anzin; and to sugar-cane mills and locomotives by Messrs. Cail; besides other applications.

Discussion.

Mr. C. E. CARDEW remarked that the eccentric now described was no doubt a very ingenious mode of working an engine expansively with a single movable eccentric — an object aimed at by a very large number of inventors, but he thought with very little success on the whole. There were a few points in the paper however which seemed to him to need further explanation. In page 423 it was stated that in the position of mid gear the centre of the eccentric coincided with a backward prolongation of the crank, and the throw was reduced to only double the lead. Also that the distribution of steam was the same as if the slide-valve were actuated by a fixed eccentric keyed upon the shaft at the proper angle. Further on it was mentioned incidentally that the spherical eccentric gave the same degree of perfection in the distribution as Gooch's link-motion. If this were the case, he thought the statement was wrong that the throw of the eccentric was only double the lead when in mid gear. From any treatise upon valve gearing, such as Zeuner's, it would be remembered that the throw of the eccentric in mid gear for all types of expansive motions was double the sum of the lead plus the lap, not double the lead only; that is, the travel of the valve on either side of its own centre of motion was the sum of the lead plus the lap. In regard to Gooch's link-motion he altogether denied that it gave a perfect distribution of steam. It used to be imagined that there was a very great advantage in that link-motion on account of its giving a constant lead; but locomotive engineers had come to the conclusion in recent years that, for locomotives doing the work for which Gooch's motion was generally used, a variable lead increasing with

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the expansion was the better of the two. It had been shown theoretically by Professor Zeuner that the lead ought so to increase that the compression in the cylinder at the end of the return stroke, at the moment of the dead point, should be about equal to the boiler pressure; and the general railway practice pointed to that conclusion as true, for it was found that drivers when running at high speeds were always fond of working with a high grade of expansion, which they would not do if there were anything bad in a variable lead. In some engines the lead increased very considerably; in passenger engines with Stephenson's gear frequently as much as $\frac{1}{8}$ inch between full gear and mid gear.

Another point to which he wished to allude was the further statement on page 423:—"for all engines that have to run both ways, forwards and backwards—such as locomotive and marine engines, steam cranes and winches, sugar mills &c.—the spherical eccentric affords a ready means of reversing." From the drawings shown of the eccentric he did not see how that statement could apply to a locomotive, in consequence of the locomotive being carried on springs. For an engine with fixed bearings, it would indeed be an excellent method; but so long as the engine was carried on springs he did not see from the drawings how any allowance was going to be made for the vertical motion of the engine on its springs—say an inch up and down. That vertical motion he was afraid would make the grade of expansion vary continually while the engine was running over a rough road. This was the case with Joy's valve-gear, which, though a very beautiful gear, had the great disadvantage in his opinion that, the rougher the road and the greater the consequent oscillation of the engine up and down on its springs, the more did the lead vary, because the whole action of the gear was due to the vertical vibration of the connecting-rod. The same objection he considered would apply to the spherical eccentric, if it were possible to adapt it to a locomotive at all.

It was also stated on page 424 that in engines with several cylinders all the slide-valves could be worked from a single eccentric, as shown in Fig. 5, Plate 59; but from that drawing it would appear that this was only the case in a special instance, where the two cylinders were

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(Mr. C. E. Cardew.)
at right-angles to each other. Supposing the cylinders were all in one line, as in the case of modern marine engines, he did not see how it could be done.

It was stated on page 424 that "the distribution is consequently attended with the same imperfections as in the case of the link-motion, namely an excessive compression when the steam is cut off early in the stroke. With a second cut-off slide mounted on the back of the main slide-valve, and worked by a second spherical eccentric, as high a degree of expansion as in the Meyer expansion gear can be obtained." These remarks might apply very well to certain classes of marine engines, but not to locomotives. As a matter of fact, on the continent, where the Meyer gear used to be much in favour for locomotives, he understood that it was now taken out more and more every year, and that engineers were reverting to the Stephenson, the Gooch, the Allan, and other forms of simple link-motion.

Mr. ROBERT S. BOYER noticed a statement on page 424 that, if applied on board ship and driven in a rough sea by any auxiliary engine available, the nut on the screwed sleeve of the eccentric would prevent the main engines from running away whenever the screw came out of the water, and would keep them working steadily at their normal speed. In a rough sea he should imagine on the contrary that the result of such an arrangement would be to check the main engines too suddenly, and so to produce violent shocks and perhaps cause a break-down. There would also be considerable trouble he thought in working such a complicated arrangement as was indicated in Plate 60 for working two engines from a single eccentric; he did not think that practically it could be done.

Mr. RALPH COLLENETTE observed that on page 425 the wear and tear were spoken of as being insignificant, and it was stated that the wear occurred only between the rim of the eccentric itself and the eccentric strap. There would however be a considerable amount of wear he imagined on the flats of the shaft driving the eccentric, especially when the engine was reversed frequently. The leverage

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at that part being very slight, he should expect a considerable amount of wear there.

Mr. HENRY LAWRENCE mentioned that in some small compressed-air locomotives without springs, built for underground haulage in collieries, he had been driven into using a loose eccentric for reversing, because there was not room enough for the ordinary reversing gear with the links and the four eccentrics; and a spherical eccentric had accordingly been schemed out for the purpose, very much after the fashion of that now described, except perhaps that there was a little less complication about it, as the screws here shown had not been required. So far as the trials in the shops were concerned, it seemed to answer very well; but in the mine, owing to the accumulation of dust, it did not act very well. It would be remembered also by some of the members that a similar motion had been brought out by Hackworth of Darlington many years ago.

Mr. ALEXANDER ALLAN did not think the spherical eccentric was suitable for locomotives. The flats on the axle would very soon get loose by the motion of the engine and by sand from the road, as in the various loose and wedge-shifting eccentrics of fifty years ago. It was an ingenious contrivance, but he did not see that it was any great improvement. The first single fixed eccentric to work both ways was Carmichael's, which he had put on locomotives in 1837; he had also applied it in 1840 on the Grand Junction Railway, but with the motion from the connecting-rod (as in Joy's gear), and with short eccentric-rod vertical in order to obtain more lap and lead.

Mr. JOSIAH MCGREGOR considered the arrangement as far as the motion went was a very good adaptation of the eccentric to working expansively; but the appliances employed to effect that object he was afraid were of an impracticable kind. There were two principal ways of effecting expansion, namely by variation in the travel of the valve, and by variation in the angle of the eccentrics.

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(Mr. Josiah McGregor.)

The former was the better of the two; and that appeared to be the effect of the arrangement now described. It somewhat resembled one that was common some time ago for working a slide-valve from a single eccentric by means of a sleeve on the shaft and a helical slot in the sleeve, whereby the valve was reversed from full head gear to full stern gear, at which positions the motion was of course that of a single eccentric; the objection to that plan was that the travel of the valve was constant throughout the intermediate positions, and the expansive effect was by variation in the angle of the eccentric. Upon that arrangement the spherical eccentric now described was an improvement in principle, inasmuch as it produced a variation in the travel of the valve and thereby effected expansion. He agreed with Mr. Cardew that in mid gear the travel would be double the sum of the lap plus the lead, and not double the lead merely as described.

Mr. W. SILVER HALL referred to the statement on page 423 of the paper, that "with a single eccentric accordingly the same degree of perfection in the distribution is here obtained as by Gooch's link-motion with stationary link." In the intermediate positions between full forward and full backward gear he believed it would be found that the spherical eccentric would give the same motion as was obtained from the various points of expansion in the Stephenson link, and not in the Gooch link. There appeared to him to be difficulties in the way of applying the spherical eccentric to locomotives, not only from the play of the bearing springs, which had been already alluded to, but also because he did not see where it would be possible to put on the crank-shaft the longitudinal screw motion or any other motion for shifting the eccentric over. It was already difficult enough to obtain sufficient space for getting the valve-gear in between the wheels, which were the limit on either side.

Mr. WILLIAM SISSON considered the author was right in referring as he did to Gooch's link-motion, and not to Stephenson's. The geometrical principle of the gear described in the paper appeared to

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him to be that of a gear with constant lead. With regard to the travel in mid gear, which had been spoken of in the paper as being only double the lead, the French custom was to employ the word "lead" for the total advance of the eccentric from its right-angled position; whereas in this country that was called the linear advance of the eccentric, being equal to the sum of the lap and lead of the valve, the latter being the amount of opening of the steam port at the commencement of the stroke. The lead of the valve was evidently constant in this gear, because the linear advance of the eccentric was seen to be constant for every position; and as the lap of the valve did not vary, the area of the port open at the end of the stroke must also be constant. That was characteristic of the Gooch stationary link, and of the Hackworth elliptic gear; but not of the Stephenson link, and only approximately of the Allan straight link. According to the way in which the eccentric rods were connected to the link, with respect to the relative positions of the crank and the cylinder, the Stephenson and the Allan link-motions gave either an increase or a decrease of lead towards mid gear. An increase of lead was of course preferred; and this was obtained by attaching the eccentric rods to the link ends in such a way that the rods should be crossed when the crank was nearest the cylinder.

The problem of working with a single fixed eccentric had been very perfectly solved, originally by Hackworth, and subsequently still better by Mr. Charles Brown of Winterthur and Mr. Marshall of Newcastle; and he had himself used what might be called an elliptic gear with the best results. It gave a distribution superior to what could be given by the spherical eccentric, inasmuch as by using a suspension link of a certain length for the eccentric-rod end a compensation could be obtained in the up and down strokes, the cut-off being delayed just in proportion to the increased load, in the same way as was done in Joy's gear. So that, as far as the single-eccentric distribution for reversing and expansion was concerned, the question had been perfectly solved in the case of a fixed eccentric.

Ingenious though the spherical eccentric admittedly was, it was nevertheless unsuitable in the opinion of many engineers who liked to

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(Mr. William Sisson.)

have what stood hard work, lasted long, and cost little for repairs. One point that had not been alluded to was that the dust-collecting surface of the spherical eccentric was considerable. There was a large area of its surface which was peculiarly adapted to carry dust, because as soon as the engine had been reversed there was a film of oil all over the surface then laid bare, and the dust that got on it would be carried in between the eccentric and the strap at the next reversal. The contrivance seemed to him very ingenious, very pretty on paper, and very nice in a model, but altogether unsuited for the hard life that mechanical contrivances must have. They must be made at less cost than in any other country, must last long, and must cost little for repairs, or they would not meet with approval.

Mr. ROBERT EDWARDS pointed out that Dodds' wedge valve-motion, which had been used some twenty years ago unsuccessfully on locomotives and also on marine engines, was identical in principle with that now shown, though more mechanical in its construction, the throw of the eccentric being altered by a wedge above and below the crank-shaft, which was moved endways along the shaft. In practice however it was found to work loose; and it was seldom that sufficient room could be found endways on a shaft to get it in.

Mr. ARTHUR PAGET suggested that, as he understood that the author of the paper was not present from illness, he should have the opportunity of replying to the discussion in the Proceedings. He should like to emphasise the remark already made that the surfaces of the spherical eccentric which were not in work seemed peculiarly exposed to the action of dust, more particularly in locomotive engines or tram engines.

The PRESIDENT said the subject of valves and valve-motions was one which had a peculiar fascination for mechanical engineers. Had the author sent a working model, a turn or two of the handle would have greatly assisted the drawings. However the contrivance had certainly been very well explained. It had at the same time been criticised in such a manner as showed that among the members

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present there were a number who were thoroughly conversant with slide-valve motions.

He now begged to propose a hearty vote of thanks to M. Poillon for the interesting paper he had contributed. He was sorry the author had been prevented by illness from being present; and in accordance with Mr. Paget's suggestion he would be afforded the opportunity of replying by letter to the discussion.

M. POILLON, regretting that through ill-health he was prevented from attending the meeting, has sent the following reply to the remarks made in the discussion.

Having but recently been introduced, the spherical eccentric has not yet been extensively applied; but in the applications which have already been made of it, at the Anzin collieries and by Messrs. Mailliet and elsewhere, no signs of wear are as yet visible. Nor in other applications will undue wear occur, provided that the parts be properly proportioned, which is simply a question of construction. While the plan may not be applicable for all classes of locomotive and marine engines, each individual case must be considered on its own merits; there will be circumstances under which it can be used with advantage, and others where it cannot. The author is not aware of any instance in which it has been applied in England, either on compressed-air locomotives or on any other locomotive engines.

The spherical eccentric has already been long enough in use to establish its satisfactory working; and the results of its adoption have proved so favourable, that the further extension of its application can be only a matter of time.

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EXCURSIONS.*

On TUESDAY AFTERNOON, 4th August, after luncheon in the new Corn Exchange, Lincoln, by invitation of the Local Executive Committee, the Members visited the Stamp End Works of Messrs. Clayton and Shuttleworth (pages 437–440), and the Sheaf Iron Works of Messrs. Ruston Proctor and Co. (pages 441–2).

In the evening there was a Special Musical Service in the Cathedral, by invitation of the Dean and Chapter (pages 307–8, 411–12); and an Address was delivered to the Members by the Bishop of Lincoln.

A number of Works in Lincoln, of which a list is given on page 437, were opened to the visit of the Members on the afternoons of both Tuesday and Wednesday. Descriptions of various of these Works are appended (pages 437–447).

On WEDNESDAY AFTERNOON, 5th August, after luncheon in the new Corn Exchange, Lincoln, by invitation of the Local Executive Committee, the Members visited the Globe Works of Messrs. Robey and Co. (pages 442–3), Clarke's Crank and Forge Works (page 443–4), and the new Machine-Works of Messrs. William Foster and Co. (page 444).

In the evening the Members were entertained at a Conversazione in the County Assembly Rooms, Lincoln, by invitation of the Local Executive Committee.

* For their information respecting the localities visited in connection with the meeting, the Members were furnished with some interesting notes kindly supplied by local friends, of which use has here been made. The notices appended of the various Works visited were supplied for the same purpose by the respective proprietors or authorities.

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On Thursday, 6th August, an Excursion was made by special free train to Grantham and Newark. At Grantham the Spittlegate Iron Works of Messrs. Richard Hornsby and Sons were first visited (pages 447–8). By invitation of the Vicar, Rev. William Glaister, St. Wolfran's Church was then visited, and the old Grammar School adjoining. The Church has recently been restored, and its lofty spire completed to the height originally intended of 280 feet. The Grammar School was the place of education of Sir Isaac Newton; his birthplace, Woolsthorpe Manor House, is at a distance of about seven miles south of Grantham. A statue of him, erected in front of the Guildhall, was seen in passing from Messrs. Hornsby's works to the church. On the invitation of the Local Executive Committee the Members were entertained at luncheon in the Exchange Hall.

Proceeding in the afternoon to Newark, the Members visited the Newark Boiler Works of Messrs. Abbott and Co. (page 448–9), and the Trent Iron Works of Messrs. W. N. Nicholson and Son (page 449). The route from one works to the other passes Newark Church and the ruins of Newark Castle, both of which were visited. A burst wrought-iron cannon was shown, discovered in 1878 during dredging in the bed of the river Trent; anticipating the form of modern guns, it is conjectured to be one of the earliest pieces of ordnance made, and to have been probably used as far back as 1428 or even 1346.

In the evening the Institution Dinner was held in the new Corn Exchange, Lincoln, to which a large number of guests were invited.

On Friday, 7th August, an Excursion was made by special free train to Gainsborough and Doncaster. At Gainsborough the Britannia Iron Works of Messrs. Marshall Sons and Co. were visited (pages 449–453), where the Members were afterwards entertained at luncheon by invitation of the Local Executive

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Committee. Also the Ashcroft Saw and Planing Mills of Messrs. H. Newsum and Co. (page 453). On the invitation of Sir Hickman Beckett Bacon, Bart., lord of the manor, the Old Hall was also visited.

In the afternoon proceeding to Doncaster the Members visited the Locomotive Works of the Great Northern Railway (pages 453–5), through which they were conducted by the locomotive superintendent Mr. Patrick Stirling, by whom they were invited to refreshments before leaving.

In the evening on returning to Lincoln the Members were invited by the Rev. Precentor Venables to visit the Cathedral under his guidance.

On SATURDAY, 8th August, an Excursion was made by special free train to Grimsby and Frodingham. At Grimsby Docks the Members were received by Lieut.-Colonel Hutton, director of the Manchester Sheffield and Lincolnshire Railway; Mr. Edward Ross, secretary; Mr. Jack Sutcliffe, shipping agent; Mr. W. Alford Green, port-master; Mr. George Cartwright, engineer to the docks; and Mr. George Clarke, superintendent engineer, steamship department: by whom they were conducted round the Docks (pages 455–7). Before leaving they were invited to refreshments by Mr. Jack Sutcliffe.

Proceeding to Frodingham, where they were received by the Right Hon. Lord St. Oswald and the other members of the Frodingham Local Committee, the Members visited the ironworks and ironstone pits described in Mr. Dove's paper (page 413); and were entertained at luncheon by the mine owners and ironmasters of the district.

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WORKS IN LINCOLN

OPENED TO THE VISIT OF THE MEMBERS.

Clayton and Shuttleworth, Stamp End Works.
Ruston Proctor and Co., Sheaf Iron Works.
Robey and Co., Globe Works.
Clarke's Crank and Forge Works.
William Foster and Co., Wellington Foundry and New Machine-Works.
John Cooke and Sons, Lindum Plough and Wagon Works.
Charles Duckering, Water Side Works.
Penney and Co., City Iron and Wire Works.
W. Rainforth and Sons, Britannia Iron and Wire Works.
Bracebridge Gas Works.
Water Works Pumping Station.
Sewage Pumping Station.

STAMP END WORKS.

These works, belonging to Messrs. Clayton and Shuttleworth, were started as a general iron foundry in 1842 on a plot of swampy ground about 1½ acres in extent, situated between the river Witham and the Sincil drain, and bounded on the east by a cut from the Witham, terminating in a small dry dock adjoining the Sincil drain. When the manufacture of portable engines was commenced in 1845, new shops were erected, which were added to and enlarged year by year as the business increased; but up to 1853 the works were wholly confined to the site on the west side of the dry dock. About this time the dock was filled up; but the cut from the Witham was still left open, and for many years divided the works, which now began to grow up on the east side. This division of the works still continues; the whole of the engineering establishment is on the west side, while the shops, saw-mill, and timber yard connected with the thrashing-machine department are on the east of the cut, or rather of its former site, as the greater portion of it has been filled up and is now occupied by railway sidings; a short length, sufficient to admit and berth one barge from the Witham, has alone been retained. The commodious block of offices was built in 1860 on the newly acquired site, and was considerably enlarged in 1878.

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Owing to the swampy nature of the ground on which the works are built, the foundations are of the most expensive character; it has been necessary to drive piles, not only for the buildings, but for each separate forge, furnace, engine, or boiler, and even for most of the heavy tools. With the exception of the end walls of the iron foundry, scarcely a brick in the present works, which cover about 20 acres of ground, occupies the same position that it did in 1851.

On entering the works at the north entrance, the first shop on the right hand is the turnery, fitting, and erecting shop, under one roof. The floor area of the turnery is about 150 × 110 feet, and that of the erecting shop about 250 × 90 feet. The erecting shop is furnished with overhead travelling cranes, and a specially-designed travelling jib-crane, running on a single rail throughout the whole length of the shop. All the shafting and machinery in the turnery, fitting, and erecting shops is driven by a diagonal high-pressure engine with single 20-inch cylinder, coupled direct to the main shafting. A duplicate engine is fixed alongside, which can be coupled up in a short time in the event of a break-down or of more power being required. Steam is supplied by three boilers, 22 feet long and 6½ feet diameter, fixed in an adjoining building. These boilers also supply steam to a vertical engine with single 14½-inch cylinder, driving the machinery in the smiths' and bolt-makers' shop, and also to the steam hammers; and are fed by an exhaust-steam injector.

In close contiguity to these shops are the shop store and general store, both of ample size and conveniently furnished for their several purposes.

The smiths' shop, 150 × 115 feet, contains some sixty forges, with tyre furnace, steam hammers, punching and shearing machines, in addition to a complete set of bolt and nut making machinery, and machinery for the production of the wrought-iron travelling wheels for portable engines. It is a lofty well-ventilated building; the shafting and machinery are driven by the vertical engine already mentioned. In a shed adjoining is an auxiliary boiler to take the place of any one of the three boilers in regular use which may be laid off for repairs or other causes.

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Adjoining the smiths' shop is the iron foundry, with a floor area of about 13,000 square feet, fully equipped with hydraulic and hand-cranes and lifts; also a smaller foundry for the production of malleable castings, with a floor area available for moulding of about 3000 square feet, fitted up with the necessary stoves and annealing furnaces. The two cupolas for the large foundry are 50 feet high, and 7½ and 5½ feet diameter respectively. The blast is supplied by Ellis's and Baker's blowing machines.

The largest shop in the works is the boiler shop, 255 × 180 feet, giving an area of more than an acre. It is well furnished with all necessary machinery and appliances for the production of first-class work, and is driven by a single 20-inch vertical engine, coupled direct to the line of shafting. The greater part of the flanging of the boiler plates is done by one of Tweddell's hydraulic presses, for which the accumulator is worked by a separate pair of engines and pumps; the riveting machines are all worked by steam. Three tubular boilers, each 21½ feet long and 6½ feet diameter, supply steam for this shop.

The west boundary of the works is formed by the painters' and laggers' shop and two testing sheds; in the larger shed ten engines can be under steam at the same time; the smaller shed is used for experimental purposes. The other principal shops in the engineering department are the brass foundry, pattern shop, and stores and loading shed, all of ample size and fitted with the necessary appliances for rapid and efficient work.

The whole area of the works on the east side, with the exception of the main offices and engine stores, is devoted to the manufacture of thrashing machines, and to the storing and preparation of timber for them. The saw mill, which occupies a central position, is 150 feet long and 65 feet wide, thoroughly furnished with wood-working machines of every description, in addition to vertical and circular saws. The motive power consists of a pair of horizontal condensing engines with 17⅜-inch cylinders, and a single 12-inch cylinder horizontal engine for driving the log frame. Steam is supplied by two tubular boilers, each 21 feet long and 6 feet diameter, and one Lancashire boiler 24 feet long and 7¼ feet diameter. The turnery

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for the machine department measures about 140 × 120 feet; and in addition to the usual complement of lathes and shaping machines it contains many tools specially adapted for the work, the whole of the machinery being driven by a single 14½-inch vertical engine working direct on to the shafting, on the plan universally adopted throughout the works. The two boilers supplying steam to this engine are fed by an exhaust-steam injector. The principal machine-erecting shop, 320 × 70 feet, forms the boundary of the machine department on its west side. Another erecting shop, 300 × 40 feet, occupies a position on the north side of the timber yard, the whole forming a triangle which is bounded by shops for frame makers, painters, tinners &c., and drying sheds for timber.

To the south of the Sincil drain, on an irregularly shaped piece of land bounded by the Manchester Sheffield and Lincolnshire Railway, are situated the locomotive shed, gas works, machine store, stables, and a second large timber yard and saw mill for the stacking of round timber and its conversion into planks.

The whole of the works are most conveniently laid out for passing the raw material on from stage to stage of the manufacture, culminating in the finished engines and machines, with the least possible expenditure of time and labour. A branch line from the railway enters the works over a weighbridge into the loading shed, where by means of a hydraulic lift and overhead travelling crane the various manufactured articles are placed direct on the railway trucks. Passing through the loading shed the railway branches off into all parts of the works, conveying coal, iron, timber, or other materials to their respective destinations. Two small tank-locomotives are employed in shunting and marshalling the trains in and out. When in full work the number of hands employed, exclusive of a large staff of officials, is over 1700; a commodious mess-room, 95 × 20 feet, is provided for their use.

Besides their principal establishment at Lincoln, the firm have also works at Vienna, covering more than six acres, and employing over 600 hands; and also branch establishments in various parts of Germany, Austria, and the Danubian principalities.

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SHEAF IRON WORKS.

The works of Messrs. Ruston Proctor and Co. were established in 1840, and cover 13 acres, employing some 1400 hands. They are divided into two portions, about half a mile apart, termed the iron works and the wood works. At the former are constructed engines and boilers, and at the other thrashing machines and straw elevators.

The iron works are on the Water Side, on the south bank of the river Witham running through the city, and are connected with the railways by a siding. In this department are constructed portable, vertical, traction, and fixed engines; condensing, non-condensing, and compound engines; portable and semi-fixed compound engines; steam navvies, corn mills, centrifugal pumps, &c. The machinery is driven by engines made in the works, indicating some 300 HP. There are three melting cupolas in the foundry, with suitable cranes. In the boiler shop are several hydraulic riveters and a hydraulic flanging machine, bending rolls, &c.; for manipulating heavy pieces there is a large travelling crane with a number of jib cranes; also a tower with requisite tackle, under which Cornish boilers are riveted up. In the smiths' shop are more than fifty hearths, steam hammers, faggoting furnaces for making up scrap iron, nut and bolt forging machines, &c. The fitting and erecting shops cover about two acres; along one side is the casting store, and along the other a stock of boilers. That part nearest the castings is occupied by the fitters; in the centre of the shop are placed the drilling, slotting, shaping, boring machines, and lathes; the other side is used for erecting. On the occasion of the visit of the Members, one of the steam navvies was exhibited in operation, performing its movements in the same way as in the work of excavation, as described in Mr. Ruston's paper (page 349), except that it was not actually excavating.

The thrashing-machine works are also on the river Witham, but higher up and near the Midland Railway station. Here is the necessary wood-working machinery, with other tools for finishing the ironwork required; also the stock of timber. The works are driven by engines of 200 HP. The new pattern thrashing machines here constructed have the driving motion of the shoes and shakers

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arranged without cranks. A lifting bridge is in course of construction across the river, to join the siding and complete the connection with the railway.

GLOBE WORKS.

These works were established by the late Mr. Robey in 1852, and now stand on an area of 13 acres, employing 1100 hands, mainly devoted to the manufacture of steam engines, pneumatic, hydraulic, electrical, and mill machinery. To facilitate the output of the work, the shops have lately undergone considerable extension and rearrangement, with a great addition of modern labour-saving tools. Railway sidings are in communication with the Great Northern, Great Eastern, Manchester Sheffield and Lincolnshire, and Midland Railways, from which the raw material is sent direct to the several departments. The principal shops and yard are lighted by electricity.

In the foundry, which covers an acre of ground, the core stoves are heated by gas, and the lifting is mainly done by means of hydraulic cranes. To ensure good castings, the cupolas are fitted with receivers, and all small castings are dressed by a rotary machine. One of the main spans of the foundry is traversed by an overhead crane, which is connected by a line of rails whereby the castings are conveyed to the fitting shop. This shop is high, well ventilated, and lighted by electricity.

The boiler shop is the largest shop on the works, and covers an acre and a half. It is in communication with the main-yard line, where the plates are introduced, and stored in their order for various sized boilers. The hydraulic system is extensively employed for flanging, riveting, and lifting. The shop shafting is driven by three Robey engines, which are coupled direct on the shaft; they are supplied with steam by boilers of locomotive type, which receive their heat from the waste gases from the plate furnaces.

In the smiths' shop a fixed engine is coupled direct to the rolls, which roll a special iron for rivets. One end of the shop is devoted to large forgings and crank-bending for engines; while the other is given to small work, and bolts and nuts, which are here screwed and tapped.

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The erecting, fitting, and machine shop, covering more than an acre of ground, has extensive galleries the full length for light tools. The main shafting is driven by two 30-HP. Robey fixed engines. Many of the tools here, as well as in other parts of the works, are of the firm's own make, being designed for their special class of manufacture. In one part of this shop are large engines in various stages of progress, fixed, portable, traction, vertical, and horizontal; also sugar machinery, mine pumps, large centrifugal pumps, and miscellaneous mining machinery. Some heavy tools are here fixed for dealing with the massive cast-iron frames and bed-plates of fixed engines. Another section of this shop is set apart for roller mills for flour-milling, dynamos, tea machines, and sawing machinery. The semi-portable winding engine with wrought-iron foundation, described in Mr. Richardson's paper (page 373) and referred to in page 390, was shown under steam on the visit of the Members; and the combined centrifugal and electrical governor with compensating arrangement attached, as described in Mr. Nevile's paper (page 385), was also seen.

The north side of the works is chiefly devoted to the manufacture of thrashing machines and agricultural machinery, and two shops to flour-mill dressing machinery.

CLARKE'S CRANK AND FORGE WORKS.

These works were established in 1860, for the manufacture of bent cranks from straight bars, by Mr. Edward Clarke, who in 1872 introduced his hydraulic crank-bending machine which produces superior work to that obtained by the hand process. In 1876 the works were acquired by the present company, who have extended them considerably by the addition of a forge, with two steam hammers by Messrs. Nasmyth Wilson and Co. of Patricroft, and one by Messrs. John Musgrave and Sons of Bolton. A large hydraulic forging-press, by Messrs. Fielding and Platt of Gloucester, for shaping suspension-bridge links, is believed to be the only machine in this country that is specially adapted for this class of work. A high-speed rotary engine for electric lighting, by Messrs. Fielding and Platt, was seen at work on the visit of the Members. The works

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employ about a hundred men, and cover 2¼ acres; and are in immediate connection with the Great Northern and Great Eastern Railways.

WELLINGTON FOUNDRY, AND NEW MACHINE-WORKS.

The manufacture of portable and other steam engines, boilers, thrashing machines, agricultural and general machinery, was commenced by the late Mr. William Foster in 1856, on the premises of his large steam flour-mill, now known as the Wellington Foundry, Waterside North. Engineering gradually superseded the milling, and absorbed the whole of the premises. On his death in 1876 the present company was formed for carrying on the business.

The old works being found inadequate to the growing trade, five acres of land were acquired in 1883 on the Derby Grounds, where an extensive range of shops for the manufacture of thrashing machines &c. has been erected, together with a saw mill, wood-drying sheds &c., which are now in full operation. An extensive foundry and blacksmiths' shop are approaching completion, but at present are only making castings and forgings for the machine department; they are sufficiently large however to supply also the engine department, which is intended to be removed to the new premises as soon as possible. The new buildings have been specially designed for the purposes for which they are intended, and are light, airy, and comfortable for the men. They are furnished with an almost entirely new plant of tools, and with appliances for saving labour and material, by eminent makers. About two hundred hands are employed.

WATER SIDE WORKS.

These works, established in 1845 by the late Mr. Richard Duckering as an iron and brass foundry, have continued to grow steadily, and now embrace also the business of a general engineer and millwright. The number of hands employed exceeds eighty; and the works cover a tolerable area, with ample space remaining for further development.

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CITY IRON AND WIRE WORKS.

At the above works Messrs. Penney and Co. carry on the business of machinists, iron founders, and wire workers, employing about 120 workmen and boys. The chief speciality of manufacture is their adjustable corn-screens, which since their introduction have been almost exclusively used by all the leading thrashing-machine makers in this country, Messrs Clayton and Shuttleworth having continued to use them from the first. The meshes of these screens, being capable of very accurate adjustment, may be set to treat all sorts and conditions of grain and seeds. They are constantly being employed for such purposes as the following:—the cleaning of wheat, barley, oats, rye, and similar grain; the sorting of coffee and cocoa berries; the sifting of tea; the screening of peas, beans, maize, &c.; the grading of wheat into two or more regular sizes for the purposes of roller-milling. Upwards of 27,000 have been made up to the present time, and the manufacture proceeds at the rate of about 40 to 50 per week. The shop in which these screens are made has only recently been built. It is 200 feet by 40 feet, and forms two lofty workshops, one above the other. The light screen-work is carried on in the upper storey; the lathes, drilling and slotting machines, &c., are fixed below. There is also a good foundry and joinery.

BRITANNIA IRON AND WIRE WORKS.

At these works Messrs. W. Rainforth and Sons employ between seventy and eighty hands, principally in the manufacture of corn screens both rotary and flat, and agricultural implements generally. The plant consists of two engines, together with lathes, slotting machines, drills, steam hammer, and other tools usually employed in the manufacture of agricultural machinery and wire work.

BRACEBRIDGE GAS WORKS.

These works, belonging to the Lincoln Gaslight and Coke Co., are situated about a mile and a half south of the city. They have recently been re-modelled at a cost of about £30,000, and are replete

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with every modern improvement. The works are equal to the production of one million cubic feet of purified gas per day. The shunting and coal hoisting, as well as the raising of purifier covers, are done by hydraulic power. A new gasholder of half a million cubic feet capacity is now in course of construction by Messrs. W. R. Renshaw and Co., of Kidsgrove. The works are under the management of Mr. John Carter.

LINCOLN WATER WORKS.

About 1½ miles west of the city is the waterworks impounding reservoir of 23 acres area, which forms an ornamental lake in the grounds of Hartsholme Hall. About a mile east of the reservoir are the filter beds and pumping machinery. There are three engines, one of which is the first compound engine that was made on Sims' plan, having the high and low pressure cylinders continuous with each other. A 25-inch cylinder is fixed on the top of a 50-inch cylinder, and the two pistons are on one piston-rod, the space between them being at all times open to the condenser. The length of stroke is 8 feet, and the 12-inch plunger-pump has a stroke of 7 feet. This engine was made in 1836 by Messrs. Harvey, Hayle Foundry, Cornwall.

The next engine is a 36-inch single-cylinder double-acting with 8 feet stroke, made in 1862 by Messrs. Williams, Perran Foundry, Cornwall, and working a compound pump with 9-inch plunger and 12¾-inch piston. This was the first pump in which the bucket was replaced by the piston. It had been at work here for some years before a model was exhibited to the Royal Scottish Society at Edinburgh, at which time the arrangement was there thought to be novel. To this pump a relief or break clack was first applied in 1863, by cutting out one-third of the area of the clack, and covering the aperture so made with a supplementary clack hinged upon the main clack at the edge opposite to the main hinge.

The third engine is a 58-inch single-acting cylinder of 9½ feet stroke, with an 18-inch plunger-pump of 8 feet stroke. It was started in March last, having been made by Messrs. Harvey, Hayle Foundry.

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On the Cross o' Cliff hill, 1¼ mile south of the pumping station and near the county asylum, is an open service reservoir holding 1,500,000 gallons. On the opposite hill, 2 miles north of the pumping station and near the cathedral, is another open service reservoir holding 800,000 gallons; also a 6-HP. gas engine for pumping over a stand-pipe to supply the upper part of the houses situated on the top of the hill. The whole of the works are under the management of Mr. Henry Teague.

SEWAGE PUMPING STATION.

In the valley about half a mile east of the city are a pair of compound engines, made by Messrs. Hathorn Davey and Co., Leeds, for pumping the sewage on to the corporation farm. The high-pressure cylinders are 15 inches diameter, and the low-pressure 30 inches diameter, the length of stroke being 5 feet. The plunger pumps are 20 inches diameter with 5 feet stroke. These works are under the management of Mr. Henry Teague.

SPITTLEGATE IRON WORKS, GRANTHAM.

These works, established in 1815 by Mr. Richard Hornsby, now cover some 16½ acres adjoining the main line of the Great Northern Railway, from which sidings are carried into every part for convenience of receiving material at the point where it is to be used, and of loading finished goods under cover in the forwarding department. The works employ on an average about 1450 hands, including officials and clerks.

About two-thirds of their area are devoted to various engineering departments, and the large shops recently erected are completely fitted with all modern appliances. The boiler shop is 212 × 100 feet, and contains a 15-ton overhead travelling crane, complete hydraulic plant, hydraulic flanging press, and full equipment of planing, drilling, punching, shearing, screwing, bending, tapping, and boiler-plate cutting machines. The engine erecting shop is 282½ × 50 feet, and has a similar overhead crane, in addition to

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fourteen swing jib-cranes. These two shops are lit by the Brush system of electric lighting. The turneries throughout the works cover an area of 3,390 square yards, and contain upwards of two hundred lathes of various kinds, milling, drilling, planing, shaping, slotting machines, &c. The prominent manufactures are various kinds of steam engines, namely portable, semi-portable, road locomotives, tramway or rail locomotives, horizontal stationary, vertical, compound stationary, compound portable, and horizontal winding engines; Lancashire, Cornish, vertical, locomotive, multitubular, and other boilers; saw benches.

The remaining one-third of the works is employed in the manufacture of specialities in agricultural machinery, including the sheaf-binding harvester which succeeded in winning the first prize in the trials of the Royal Agricultural Society at Shrewsbury last year; also grass mowers, reapers, ploughs, thrashing machinery, turnip cutters, root pulpers, and specialities for home use as well as for the different colonies and other countries.

NEWARK BOILER WORKS, NEWARK.

These works, built in 1884 by Messrs. Thomas Abbott and Co., stand on 3½ acres of land, of which about 1 acre is covered in. The object aimed at has been to erect the most suitable works at a moderate cost for doing high-class light boiler-work. The main building, 200 feet long by 130 feet wide, is so arranged that the boiler plates are delivered by rail into the platers' hands, and all operations necessary to make a complete boiler follow on consecutively—flanging, punching, planing edges, welding, drilling, hydraulic and hand riveting, testing, and loading for despatch—without any retrograde movement. This enables a maximum of work to be done with a minimum of labour; and thus with only a hundred hands a very large amount of work is produced. All the principal machines, namely plate-rolls, punching, shearing, riveting machines, and blower for smiths' fires, are driven by separate engines, all of which take steam from the same boiler: so that any part of the

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work which may be behindhand can be kept going overtime without running the main shafting.

The foundry department is at present carried on in another part of the town.

TRENT IRON WORKS, NEWARK.

These works, belonging to Messrs. W. N. Nicholson and Son, have on one side the Midland Railway station, with sidings into the works; and on the other the Trent navigation, giving direct communication to the midland manufacturing and coal districts, and to the ports of Hull, Goole, and Grimsby. Two departments of manufacture are carried on. The general engineering part is devoted to vertical, portable, and fixed steam engines, with a rather extensive boiler department; and to bone mills, rice shellers, and other heavy and light machinery for home, foreign, and colonial use. The implement shops are devoted to the manufacture of a great variety of agricultural machines; and are arranged to take up the consecutive work of each season as it comes round:—harrows, cultivators, clod-crushers, rollers, and field implements in the spring; horse rakes and hay-makers in the summer; grinding mills and barn machinery in the autumn; and root-cutters and other food-preparing machines in the winter.

BRITANNIA IRON WORKS, GAINSBOROUGH.

These works, belonging to Messrs. Marshall Sons and Co., were established on a very small scale in 1848. At the present time they occupy a total area of over 16 acres, of which 11½ acres are covered with substantial buildings, many of them two storeys high, constructed mostly of bricks made on the spot. The nominal power required to drive the machine-tools is 400 HP., the indicated power being probably 1200 HP.; steam is supplied by boilers of 490 aggregate nominal HP. The total length of main-line shafting in the shops is

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5610 feet; and there are over 35,000 feet of belting. From 1800 to 1900 mechanics are employed, besides foremen and office staff. The works are situated on the west side of the main line of the Manchester Sheffield and Lincolnshire Railway; and an approach road leading to the railway station divides them into two parts, known as the north and south sides, which are connected by a tunnel under the road. As the station is situated on ground about 28 feet higher than the works, this facilitates the delivery of raw material brought in by the line. Finished articles are put directly on the trucks in the packing department, which is in immediate communication with the railway sidings. Although the works have been built up piece by piece as extensions have been required, the shops are so planned that the work shall as far as possible be always moving forwards in the successive stages of its progress, seldom going over the same ground twice.

The north side comprises offices, engineering department, iron foundry, and boiler shop, all arranged with a view to economising labour to the fullest extent possible. When extensive alterations now in progress are completed, the later labour-saving devices introduced will enable this aim to be even yet more fully realised.

The south side, covering a larger area than the north, consists of the smithy, the wood-working departments, and the shops devoted to the ironwork in connection with thrashing, corn-grinding, tea and coffee preparing, and other machinery. The greater part of the buildings on the south side are of bricks made on the spot in Foster's kiln, the output being about 60,000 bricks per week when working one press only.

The engine erecting and general tool shop is a building of three bays, covering a total area of 57,644 square feet; the centre span is 56 feet, and the two others 38 feet each, with galleries all round for lighter tools. Power is supplied by three 18-HP. wall engines, for which steam is furnished by two 40-HP. Lancashire boilers. There are considerably over 200 machine-tools, of which a large proportion are of special make to suit the particular work required. The shop is lighted both by Crompton's electric light and by gas, and is heated by steam in hollow columns. On the ground floor and also connected

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with the gallery are two smiths' shops for making and grinding the tools pertaining to the many special labour-saving machines used. Adjoining are the engine stores, where the finished parts of engines are kept on two floors, the heavy parts on the lower floor and the lighter details on the upper. The paint shop, adjoining the principal testing shed, has a floor space capable of accommodating 24 engines at a time.

The foundry, including the fettling shop at the north end, has at present an area of 20,420 square feet. In the east bay there are two 20-ton jib-cranes; also smaller hand-cranes, a 10-ton overhead traveller, the usual sand-mixing machinery, and two 48-inch Lloyd fans. Extensions in progress will when completed increase the foundry area to 59,700 square feet. The clay excavated for these extensions is being made up into bricks on the premises.

The boiler shop, entirely remodelled within the last few years, covers an area of 70,820 square feet, and is built entirely of brick, and divided into seven bays, each for a separate branch of work. At one corner is the entrance for railway trucks, which are brought direct into the boiler-plate stores, where the plates are unloaded by means of two 2-ton travelling jib-cranes, and are deposited in rows according to size and quality. At the other end of the same bay is a multiple punch, which will take in and punch boiler plates up to 12 feet long and 4 feet wide, and will punch 27 holes at a time, with any pitch and with an accuracy of 1-5,000th of an inch. The next bay contains large punching and shearing presses and other general tools, and a special 4-spindle drill for firebox frames; also a large plate-furnace, a 4-ton overhead travelling crane, and a number of 1-ton jib-cranes attached to columns and walls. The heat of the plate-furnace is utilised for a 40-HP. Lancashire boiler made entirely of steel; and the application of waste gases for steam generation is generally carried out throughout the works. The next bay contains another large plate-heating furnace, in connection with a 100-ton hydraulic flanging press, which is the first Piedbœuf flanging press erected in England for commercial purposes. The next bay is for machine-riveting, and contains four steam and three hydraulic riveting machines with the necessary rivet furnaces; also a special boiler-shell

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drilling machine. The roof of this bay is higher than of the rest, so as to cover a riveting tower for riveting up large Cornish and Lancashire boilers on end; the tower is provided with two 15-ton steam lifts, so that loads up to 30 tons can be conveniently handled. The hand-riveting bay comes next, in which there are several special tools, including a man-hole milling machine, and a 3-spindle horizontal drill for drilling through boiler shells and flanges of tube-plates when in position. At one end of this bay is a water-tight gallery, made entirely of iron, where all boilers of the locomotive and vertical type are tested by hydraulic pressure before leaving.

In the general smithy are 73 fires, nine steam-hammers, and two drop-hammers, besides a large number of foot olivers, punching and shearing presses, and nut-forging, drilling, and stamping machines. Blast is supplied by two 48-inch Lloyd fans. The machinery is driven by a 12-HP. horizontal engine and two 14-HP. vertical engines. Two 40-HP. Lancashire boilers supply steam for the engines and steam-hammers. Balling furnaces are about to be put down for making special forgings of remade iron. A building at the end of the smiths' shop is being fitted up for the eight electric-light engines and four dynamo machines. The engines are vertical, 14 HP. each, made in the works, a duplicate being provided to each machine; and steam is supplied by two Lancashire boilers in an adjoining house.

The fitting and machine-tool shop is arranged for preparing the general ironwork for the thrashing-machine department, and also includes mill work, saw benches, tea and coffee machinery, steam capstans, shafting, pulleys, &c. The machinery is driven by two 35-HP. horizontal engines made in the works, supplied with steam by three 50-HP. underfired multitubular boilers. There are 67 lathes, and about as many other machine-tools of various kinds, all of modern make. In the gallery are milling machines, lathes, emery wheels, &c.

The thrashing-machine framing and elevator department contains 42 double and 19 single benches, with the necessary tools and appliances. Above it is the thrashing-machine erecting shop, 313 feet long and 63 feet wide, containing 25 double and 32 single benches, with hoists and runners, circular saws, drilling machines,

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and all other necessary tools. These shops are in connection with the machine stores, which contain a floor area of 14,229 square feet. The saw mill is about 130 feet square, divided into four bays, and completely equipped with wood-working machinery of all kinds.

ASHCROFT SAW AND PLANING MILLS, GAINSBOROUGH.

These works, built about three years ago by Messrs. H. Newsum and Co., are laid out upon the most modern and improved plan, and are furnished with special machinery for the preparation of English and foreign timber. They enjoy special facilities for carrying on this particular business, being situated upon the banks of the navigable river Trent, and connected with the Great Northern and Great Eastern Railways by sidings, laid throughout the yard and timber sheds; a steam locomotive crane is used for loading timber. The saw mill is 250 feet long by 60 feet wide, and is fitted up with all modern wood-preparing machinery and labour-saving appliances.

GREAT NORTHERN RAILWAY LOCOMOTIVE WORKS, DONCASTER.

The shops of the locomotive department of the Great Northern Railway at Doncaster were started in 1852, and have from time to time been increased, until at present 2500 men are employed within the gates. Gas is made in the works for supplying both the works themselves and the adjoining station platforms, &c. The whole extent of ground covered by roof amounts to 16 acres; and the areas of the principal shops are as given below:—

	Square Yards.
Smithy and Forge	2,460
Locomotive Fitting Shops, Erecting and Tender Shop	12,795
Iron and Brass Foundry with Pattern Shop	2,305
Carriage and Wagon-building Shops, Sheds, &c.	27,906
Boiler Shop	3,333
Timber Drying Shop	3,333
Stores	4,104
Grease Works	561
Offices	534

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*The smithy is a shop of L shape in plan, containing a large number of fires and nine steam-hammers, under which a great many forgings are made in dies. There are also Ryder swaging machines for making bolts, with Horsfall's nut and bolt machines. Coupling chains are welded in dies under the steam-hammer, the butt ends of the links being overlapped without scarfing, and forced together in the dies in welding. The side-frames of locomotives are here welded up. Adjoining is a tyre shed, where the tyres are put on the wheels, and where also are made the steam-hammers for use in the works. An adjacent spring shop contains smiths' fires, furnaces, and steam-hammer; a machine for forging, punching, nibbing, and pointing the spring plates at one heat; and a steam testing-machine that will test up to 10 tons. In the forge are five steam-hammers, from 2 tons upwards, one of which is used for wheel bossing.

The fitting shop contains the usual heavy tools for turning wheels, planing frame-plates, boring cylinders, turning crank-axles, and for other heavy work. At one end are the hydraulic presses for pressing wheels on their axles. An upper floor carries the lighter tools. In the engine erecting shop a steam traversing platform works all down the centre, for carrying the engines to and from the pits, which are ranged in a row down each side. Over each row of pits runs a 3-ton travelling crane; in addition to which there is over one row a 50-ton travelling crane. For adjusting the bearing springs to distribute the required load upon each wheel, a large weighing machine is employed, having eight tables, whereby each wheel of an eight-wheeled locomotive can be weighed individually. Adjoining is the tender erecting shop.

In the foundry, which has two cupolas and the usual cranes and other appliances, the castings include a number of cast-iron chimneys of $\frac{5}{8}$ inch thickness, which are found to last much longer than the ordinary boiler-plate chimneys used on locomotives.

The carriage and wagon-building shops, of which the latter covers two acres and the former nearly as much, contain a large number of

* This notice has been partly condensed from one which appeared in *Engineering* on the date of the visit.

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wood-working machines of all kinds; repairs of carriages and wagons are also executed. Between these shops is the timber drying shed.

The boiler shop is in two bays, with a travelling crane in each. At one end are the accumulator and pumps for hydraulic riveting. One of the stationary hydraulic riveters has a hydraulic crane attached to it. A portable hydraulic riveter is used for the foundation rings of fire-boxes and for girder work.

The stores include one in which is kept a standard pattern of every part made.

GRIMSBY DOCKS.

The Grimsby Docks comprise the Royal Dock, Union Dock, Alexandra Dock, Old Fish Dock, and New Fish Dock. The engineer is Mr. George Cartwright.

The Royal Dock is 2,300 feet long and 500 feet wide, and has an area of 25 acres. It is entered from a tidal basin of 14 acres, through two entrance locks, the larger of which is 300 feet long and 70 feet wide with 26 feet depth of water on the sill at high water of ordinary spring tides. At the time of its completion in 1852 this lock would accommodate the largest steamships of the royal navy. The smaller lock is 200 feet long and 45 feet wide. Each lock has two pairs of pen gates and one pair of flood gates, all made of English oak and greenheart, and worked by hydraulic power. The dock walls are built on arches of 27 feet 4 inches span; the arches are formed of four half-brick rings, and are supported on masonry piers 6 feet thick, which are built on piled foundations.

Attached to the Royal Dock is a graving dock 400 feet long, 350 feet on the blocks, and 87 feet wide at the top. The entrance is 70 feet wide, and the depth of water on the sill is 20 feet. The dock is emptied to low-water level by a culvert, and the remaining water is pumped out.

The quays, and the adjoining transit sheds and warehouses, are provided with eighteen hydraulic cranes of from 1 to 5 tons

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power, and five hydraulic hoists, as well as numerous hand cranes, the largest of which is capable of lifting 20 tons. The hydraulic power for working the lock gates and cranes is derived from the tower between the two entrance locks. The total height of the tower from the quay to the top of the lantern is 300 feet; to the bottom of the water tank the height is 214 feet, and the depth of water in the tank when full is 8 feet. The water is pumped into the tank by a pair of engines of 250 horse-power. The tower is built upon a solid block of masonry, which rests upon piled foundations. On the west side of the dock, sheers to lift 70 tons have recently been erected, the hydraulic power being furnished by an accumulator of 17 inches diameter and 17 feet lift, which is worked by a steam pumping engine of 40 horse-power.

The Union Dock, completed in 1879, forms a connection between the Royal and Alexandra Docks. It is 96 feet wide, and has an area of 1¼ acres. The dock walls vary in thickness from 20 feet to 26 feet, and rest upon piles. The lock is 45 feet wide, and the depth of water on the sill is 21 feet. The gates, the swing bridge over the lock, and the capstans on the lock side are worked by hydraulic power from the accumulator above mentioned.

The Alexandra Dock is an enlargement and extension of an old dock, which was originally formed early in the present century by the holding up of the waters of an inland stream called the river Freshney. It is 48 acres in extent, and 21 feet deep. In addition to the entrance from the Union Dock it communicates with the Humber by means of a lock 145 feet long and 35 feet wide, with a depth of 18 feet on the sill at high water. The dock is principally used for the import of timber, sleepers, and pit props.

The two Fish Docks have a total area of 23 acres, and are entered by two locks having a width of 20 and 30 feet respectively. The fish market alongside these docks is 1950 feet long, and varies in width from 37 feet to 80 feet. In addition to this there are two stages for the accommodation of the fishing trade, having a total area of 9,236 square yards; and a further extension is now in course of construction, which will give an additional area of 3,360 square yards.

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A graving dock which will hold ten smacks at a time is entered from the outer or Old Fish Dock. Its length is 400 feet, width 50 feet, width of entrance 30 feet, and depth of water on sill 18½ feet.

There are two coal drops in the Alexandra Dock, and two in the Royal Dock, each of which is capable of loading two ships simultaneously at the rate of 100 tons each per hour.

The docks and their entrances are dredged by means of five powerful steam dredgers, and one Priestman's crane and bucket. Two of the dredgers are hopper-dredgers, capable of carrying respectively 300 and 500 tons, and are fitted with screw propellers.

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MEMOIRS.

Henry Charles Fleeming Jenkin was born on 25th March 1833, at Hythe in Kent, where his father, Capt. Jenkin, R.N., was on coast-guard service. He received his early education at Jedburgh and at the Edinburgh Academy, afterwards going to school in Frankfort-on-the-Main and in Paris. He then studied for about two years in the University of Genoa, where he graduated as master of arts in the year 1850. After serving an apprenticeship in a locomotive establishment at Genoa, he returned to England in 1851, and served an apprenticeship of three years in Manchester at Messrs. Fairbairn's engineering works, from 1851 to 1854. He was then employed successively by Mr. Hemans in railway surveying in Switzerland, at Messrs. John Penn and Sons in the drawing-office, and by Messrs. Liddell and Gordon in railway work. In 1857 he entered the employment of Messrs. Newall at Birkenhead, to whom was entrusted the manufacture of the wire required for the first Atlantic cable; and was placed by them in superintendence of the machine construction of their factory, in which position he was engaged in fitting up steamships for laying submarine cables and in designing picking-up and paying-out machinery. He had general charge of the electrical testing of the cables during their manufacture; and as chief electrical engineer personally accompanied many cable-laying expeditions, including that for laying the first cable between Malta and Alexandria. In 1859 he gave evidence before the royal commission on submarine telegraphs, on which subject he had become an authority. From 1861 he acted as reporter to the committee then formed of the British Association for the purpose of determining what standards should be used in making electrical measurements; and in the same year entered into a civil engineering partnership in London with Mr. H. C. Forde. In 1862 he read a paper to this

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Institution upon the construction of submarine telegraph cables (Proceedings 1862, page 211). In 1865 he was elected a Fellow of the Royal Society; and in the following year was appointed professor of civil and mechanical engineering in University College, London, which position he held until 1868, when he was elected to the similar chair newly instituted in Edinburgh University. In 1868 he gave evidence before the committee of the House of Commons on scientific instruction. For some years before going to Edinburgh he was associated with Sir William Thomson as joint engineer to the Western and Brazilian and Platino-Brazilian Telegraph Co., and to the Mackay-Bennett Cable Co.; and also as joint inventor in connection with the working of long submarine cables. In 1877 he delivered two lectures before the Edinburgh Philosophical Institution on healthy houses and on ventilation and warming, to introduce and draw attention to the Sanitary Protection Association of Edinburgh; which led to the subsequent establishment of similar associations in London and numerous other large towns. During the last three years of his life he devoted much attention to his system of electrical transport or haulage, which he called "telpherage." He died on 12th June 1885, at the age of fifty-two, from blood-poisoning following upon a surgical operation. He became a Member of this Institution in 1875; and was a member of the Research Committee on Friction.

Henri Edouard Tresca was born at Dunkerque on 12th October 1814, and died in Paris on 21st June 1885, in the seventy-first year of his age. He entered the Ecole de Saint-Cyr in 1832, but his taste for science led him thence in 1833 to the Ecole Polytechnique, whence he went in 1835 to the Ecole des Ponts et Chaussées. In 1841 he started as a civil engineer, erecting works for the manufacture of stearic acid and the distillation of mineral oil. At the Exhibition in London in 1851 he was entrusted with the classification of the French productions. In 1852 he was invited by General Morin to take the post of engineer in the Conservatoire des Arts et Métiers, with which his name was thenceforth associated for the rest of his life. In 1854 he succeeded General Morin in the chair of mechanics,

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and was appointed inspector of the industrial schools throughout the country, and a member of the committee by whom the appointments of teachers for the schools were made. His various experiments upon mechanical subjects, published in the Annales du Conservatoire, which was a work originated by himself, were speedily recognised as authoritative in other countries as well as France. What he himself regarded as his most important work of all was that to which during the last twenty years of his life his energies were continuously devoted, namely his elaborate investigations into what he boldly and rightly called the flow of solids. Upon this subject he gave a paper at the first meeting of this Institution in Paris in 1867, and again a further paper at the second meeting there in 1878 (Proceedings 1867 page 114, and 1878 page 301). The services which he rendered as secretary of the metre commission resulted in the adoption of the form designed by himself for the metre standards, whereby strength was combined with lightness. His singular readiness in mastering new subjects was remarkably exemplified by his connection with the Electrical Exhibition in Paris in 1881; though possessing but an elementary acquaintance beforehand with this department of science, he at once took the lead in conducting the trials there made of the various apparatus exhibited, and became an authority in regard to experiments upon electric lighting and the transmission of power by electricity. He was a Member of the French Academy of Sciences; honorary President of the French Institution of Civil Engineers; professor and chairman of council in the College of Arts and Manufactures; professor of mechanics in the Agricultural Institute; member of the Council of Technical Education; vice-president of the Society for the Encouragement of National Industry; a founder and an active vice-president of the International Society of Electricians; besides holding many other titles both of French and of foreign distinction. In 1867 he was nominated by the Council of this Institution an Honorary Life Member; and he was present at the summer meeting in Belgium in 1883, when he took part with all his wonted vigour in the various excursions.

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Institution of Mechanical Engineers.

PROCEEDINGS.

October 1885.

The Autumn Meeting of the Institution was held in the Corn Exchange, Coventry, on Wednesday, 28th October 1885, at Three o'clock p.m.; Jeremiah Head, Esq., President, in the chair.

The President said that, as the members of the Institution of Mechanical Engineers were strangers to some present, he might perhaps be allowed to make one or two remarks with reference to their present meeting. Although the Institution had been originated and developed in the same county, this was the first time they had held any meeting in Coventry. Not that the members of the Institution were totally ignorant of the industries here carried on; for from their earliest infancy they had all heard of the ribbon-weaving industry, and of the watch and clock-making industry; and latterly of the cycle industry, which he understood had now taken the lead of all the others. They also knew that Coventry was full of historical associations; although until he went through the streets that morning he had no idea that it was so large and important a city as it really was. Some of the Council were indeed almost sorry that they had not kept it in reserve for one of the Summer meetings, which lasted three or four days, instead of visiting it in an Autumn meeting, which lasted only one day. They were about to hear a very interesting paper by Mr. Phillips. The author had taken a great deal of pains in preparing a review of the cycling industry in its mechanical aspect; and the members he was sure would give this paper their careful attention. The discussion would not be confined to members, and he hoped they would have

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the benefit of the observations of local engineers and others interested in cycling. For the information of any who had not attended these meetings before, he might observe that they looked upon the questions brought before them entirely from the point of view of mechanical engineers; their only consideration was how far different mechanisms were adapted for the purposes for which they were intended; and they did not take any cognisance of questions regarding priority of invention or commercial interests.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and the following thirty-five candidates were found to be duly elected:—

MEMBERS.

George Beeton Alderson,	Alexandria.
Henry Bateman,	Rangoon.
Arthur Channing Bicknell,	Chester.
Frederick John Burrell,	Thetford.
Herbert Fuller Carter,	Huelva, Spain.
Herbert Clutterbuck,	London.
Frederick William Durham,	London.
William Errington,	Auckland, N.Z.
Joseph Fitton,	Manchester.
James Peter Franki,	Sydney.
David Greig, Jun.,	Leeds.
John Henry Harris,	London.
Henry William Hollis,	Alfreton.
John Frank Hyland,	London.
Amandus Edmund Keydell,	Cardiff.
James Moir,	Bombay.
Edwin Monk,	London.
Thomas Mudd,	West Hartlepool.

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Henry William Pearson,	Bristol.
William John Pratten,	Belfast.
William Rainforth, Jun.,	Lincoln.
James Thomas Simpson,	Calcutta.
Thomas Smith,	Leeds.
Frederick Charles Southwell,	Grantham.
Mountford Spencer,	Manchester.
George Percival Spooner,	Nagpur, India.
George Thornley,	Burton-on-Trent.
Nicholas Thomas Williams,	London.
Robert Henry Wood,	Leeds.

ASSOCIATE.

Charles Henry Moser,	London.

GRADUATES.

Henry Appleby, Jun.,	Limerick.
Walter Cleeve Edwards,	Wellington, N.Z.
John Henry Tangye,	Birmingham.
William Marsden Wakefield,	London.
Charles Drinkwater Wray,	London.

By direction of the President the following announcement was read:—

In accordance with the Rules of the Institution, the President, three Vice-Presidents, and eight Members of Council will retire at the ensuing Annual General Meeting; and the President having consented to be nominated for a second year of office, the Council present the following as the list of their retiring Members who offer themselves for re-election, and who are accordingly nominated by the Council:—

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PRESIDENT.

Jeremiah Head, ...	Middlesbrough.

VICE-PRESIDENTS.

E. Hamer Carbutt, M.P., . . .	London.
David Greig, ...	Leeds.
Joseph Tomlinson, ...	London.

MEMBERS OF COUNCIL.

Peter D. Bennett, ...	Tipton.
William Denny, F.R.S.E., . . .	Dumbarton.
Benjamin A. Dobson, ...	Bolton.
Sir James N. Douglass, ...	London.
Alexander B. W. Kennedy, . . .	London.
Edward B. Marten, . . .	Stourbridge.
Benjamin Walker, ...	Leeds.
J. Hartley Wicksteed, . . .	Leeds.

In addition to the foregoing names, Mr. Thomas W. Worsdell, Gateshead, is also nominated by the Council for election as a Member of Council, in place of Mr. Francis C. Marshall, who has resigned his seat.

Any Member being now entitled to add to the list of candidates, a circular signed by the President has already been issued to the Members of the Institution, explaining fully the course pursued by the Council on the present occasion in limiting the nominations by the Council to the above names. In this course the Council believe they are acting in accordance with the wishes of the Members generally.

The President reminded the Meeting that according to the Rules of the Institution any Member was now entitled to add to the list of candidates.

No other names were added.

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The President announced that the foregoing names would constitute the nomination list for the election of officers at the Annual General Meeting.

Mr. M. Powis Bale gave notice through the Secretary that at the next Annual General Meeting he should propose the following motion:—

That Bye-Law 22 be amended to read as follows:—"All Papers "shall be submitted to the Council for their approval, and after their "approval shall be printed and circulated among the Members at "least one week before the General Meetings; and an abstract "only of each Paper shall be read by the Secretary at the General "Meetings, or by the Author with the consent of the Council."

The following Paper was then read and discussed:—

On the Construction of modern Cycles; by Mr. Robert Edward Phillips, of London.

The President moved the following Votes of Thanks, which were passed by acclamation:—

To the Proprietors of the various Works in Coventry, thrown open for inspection, for their kindness in inviting the Members to visit their Works.

To Mr. J. Alfred Griffiths and Mr. Robert E. Phillips for the active part they have so kindly taken in preparing the arrangements for the present Meeting.

The Meeting then terminated. The attendance was 48 Members and 85 Visitors.

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Both on the morning of the Meeting and on the following day the Members had the opportunity of visiting the undermentioned Works in Coventry, by invitation of the several Proprietors:—

Bayliss Thomas and Co.'s Cycle Works, 80 Lower Ford Street.
Coventry Cotton Co.'s Spinning and Weaving Works, Foleshill Road.
Coventry Elastic Weaving Co.'s Web Works, Perkins Street.
Coventry Machinists' Cycle Works, Cheylesmore.
Griffiths and Co.'s Cycle Works, Priory Mill, Priory Street.
Hillman Herbert and Cooper's Cycle Works, South Street.
H. Hodkinson's Coventry Art Metal Works, Wellington Street.
Iliffe and Son's Printing Works, Vicar Lane, Smithford Street.
Leigh Mills Co.'s Textile Manufacturing Works, Hill Street.
Rotherham and Sons' Watch Factory, 27 Spon Street.
D. Rudge and Co.'s Cycle Works, Crow Lane.
Singer and Co.'s Cycle Works, Alma Street.
M. H. Spencer and Co.'s Reed and Slay Works, Priory Mill, Priory Street.
Starley Brothers' Cycle Works, Fleet Street.
Starley and Sutton's Cycle Works, West Orchard.

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Fig. 1. *Ordinary Bicycle.*

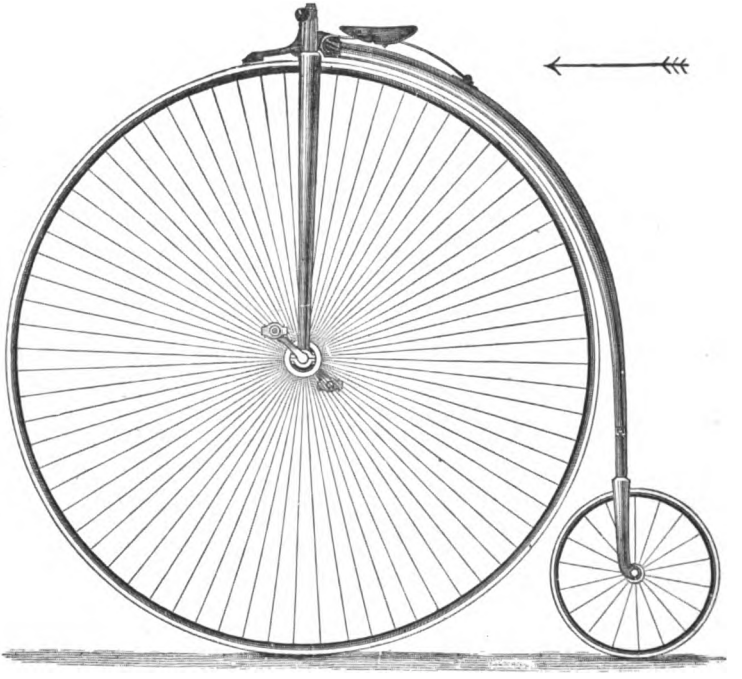
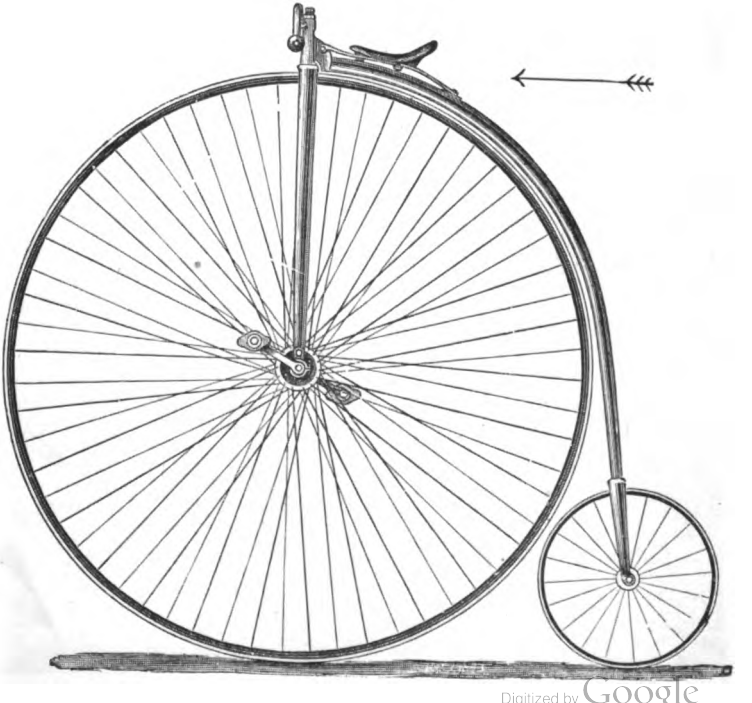


Fig. 2. *Racing Bicycle.*



(*Proceedings Inst. M. E.* 1885.)

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Fig. 3. *Suspension of spring on rubber buffers.*

Scale 1/4th

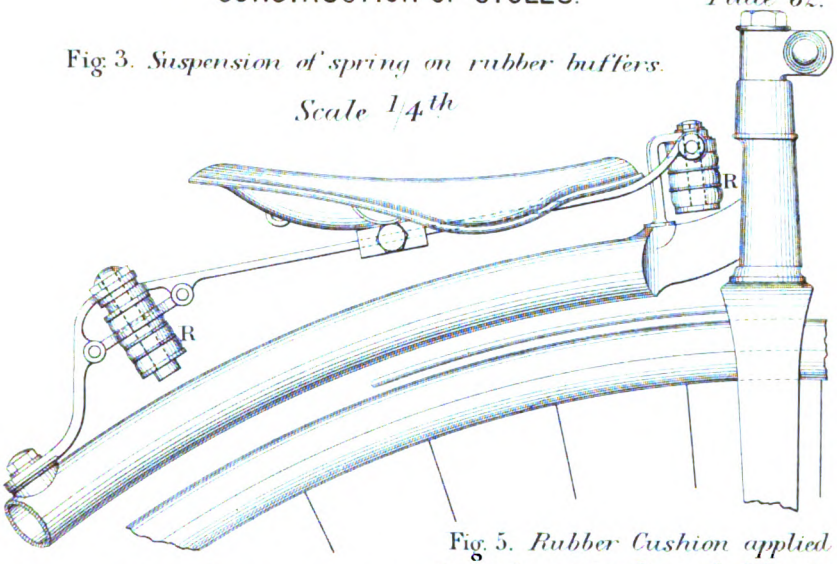
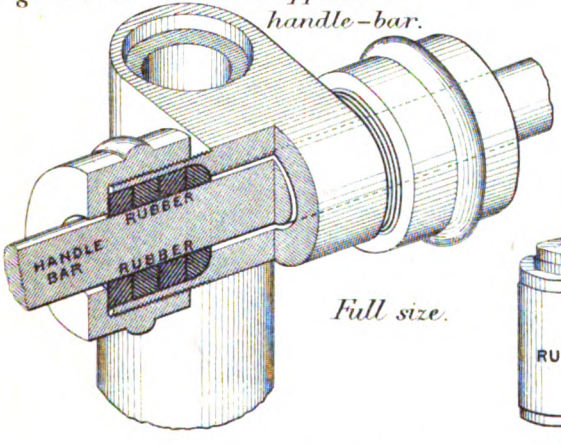
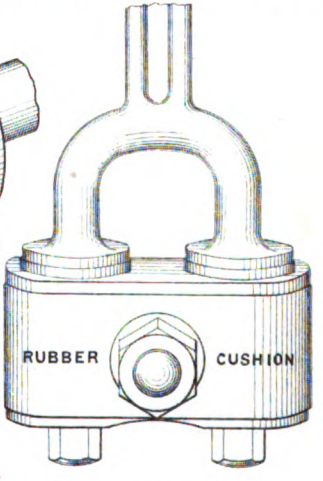


Fig. 4. *Rubber Cushion applied to handle-bar.*



Full size.

Fig. 5. *Rubber Cushion applied to steering or trailing-wheel bearing.*



Rubber Cushion applied to driving-wheel bearing.

Scale half full size.

Fig. 6. *Elevation.*

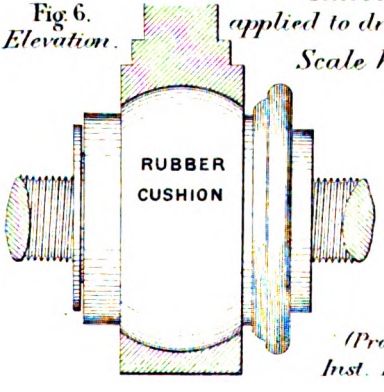
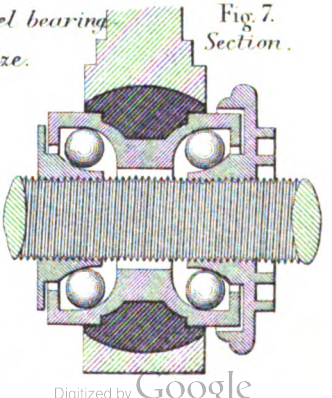


Fig. 7. *Section.*



(Proceedings Inst. M. E. 1885.)

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Fig. 9. *Dwarf Bicycle with geared rotary action.*

Fig. 8. *Spring Fork to steering-wheel.*

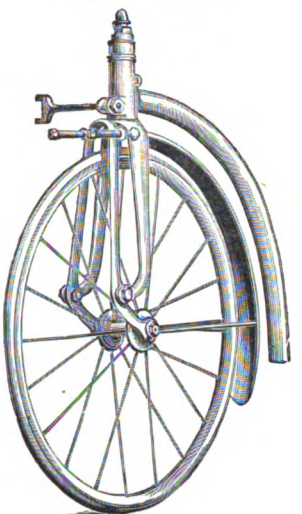
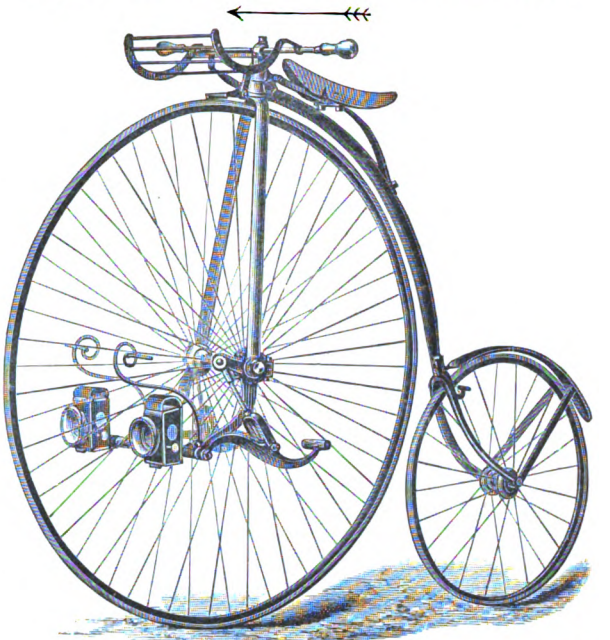


Fig. 10. *Dwarf Bicycle "Facile" with lever action.*



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Hinged Fork Ends, carrying brackets for Pedal axle.

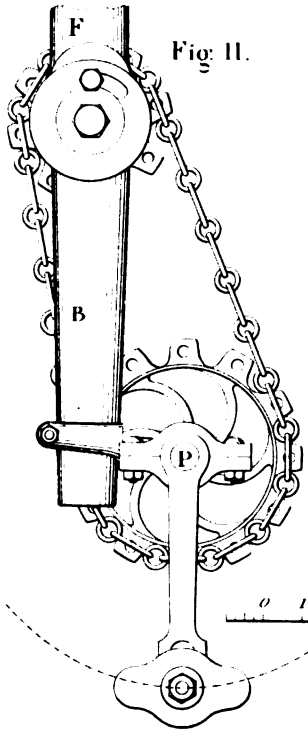


Fig. 11.

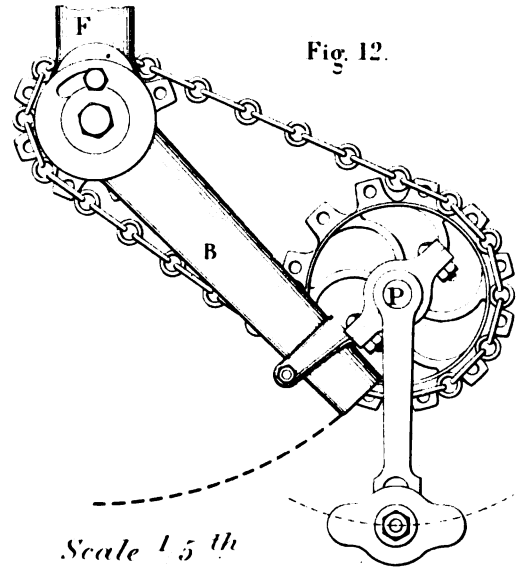
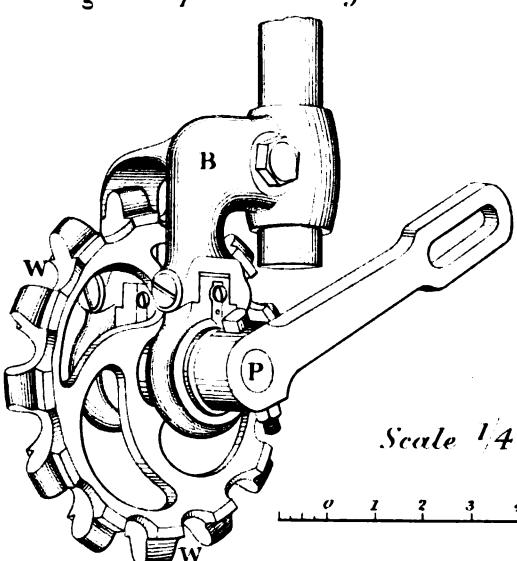


Fig. 12.

Scale 1/5 th

0 1 2 3 4 5 6 7 8 9 10 Ins.

Fig. 13. *Duplex Bearing.*



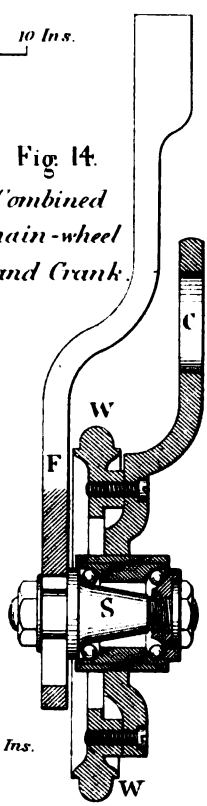


Fig. 14. *Combined Chain-wheel and Crank.*

Scale 1/4 th

0 1 2 3 4 5 6 Ins.

(Proceedings Inst. M. E. 1885.)

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Fig. 15. *Dwarf Bicycle "'Xtraordinary" with elliptical lever action.*

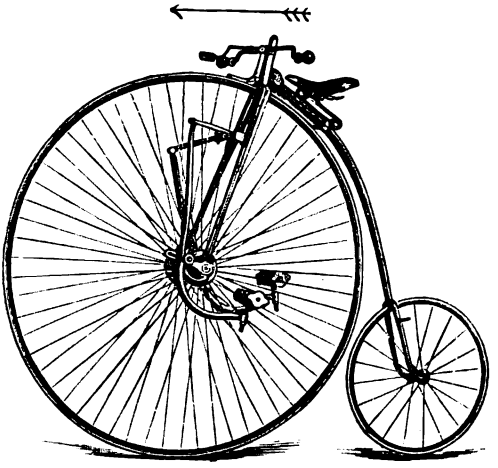
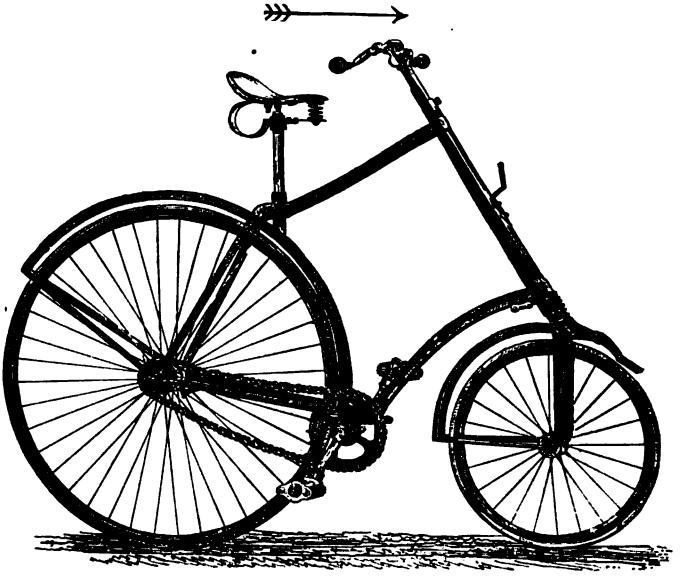


Fig. 16. *Safety Bicycle with steering wheel in front, and continuous pedal-axle.*



(*Proceedings Inst. M.E.* 1885.)

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Fig. 17. *Safety Bicycle with steering wheel in front, and pedal-axle divided.*

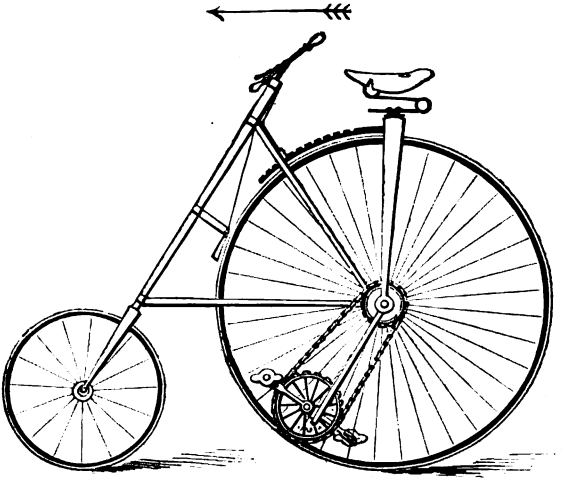
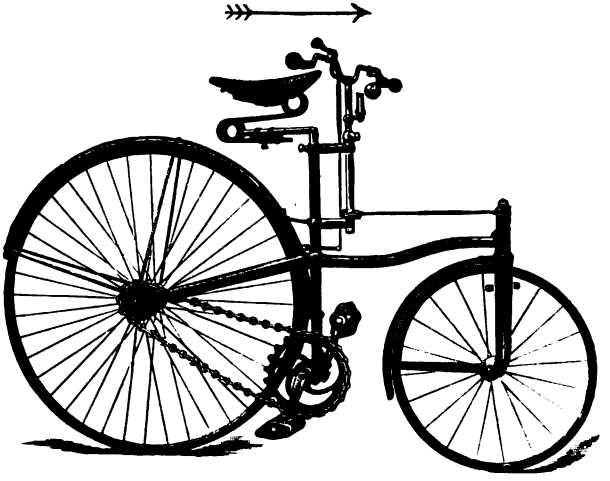


Fig. 18. *Safety Bicycle with indirect steering by levers.*



(*Proceedings Inst. M.E.* 1885.)

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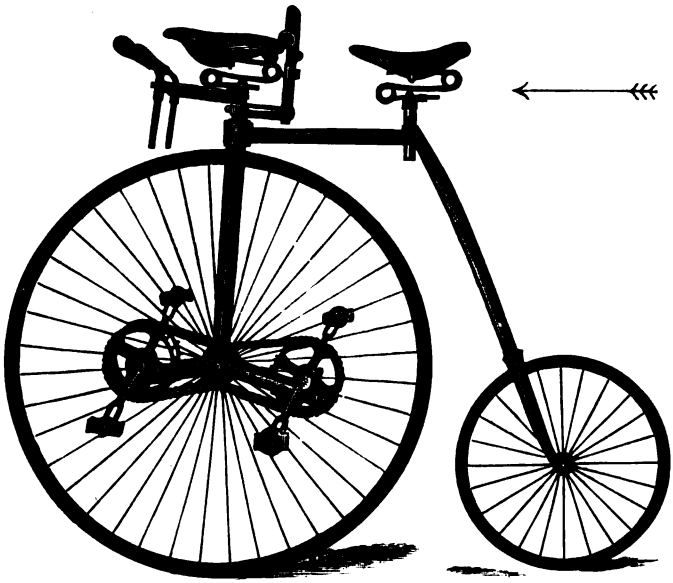
Fig. 19. *Safety Bicycle with large steering wheel.*

Fig. 20. *Later Rucker Tandem Bicycle.*



(*Proceedings Inst. M.E.* 1885.)

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Fig. 21. *Earlier Rucker Tandem Bicycle.*

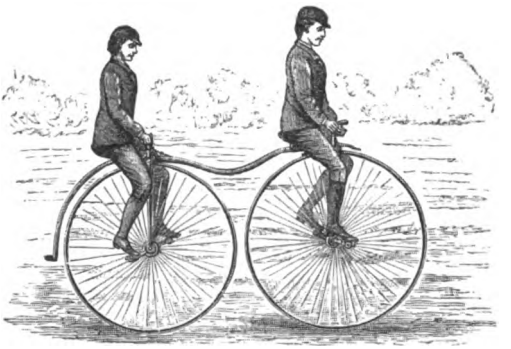


Fig. 22. *Tricycle modified from* Fig. 21.

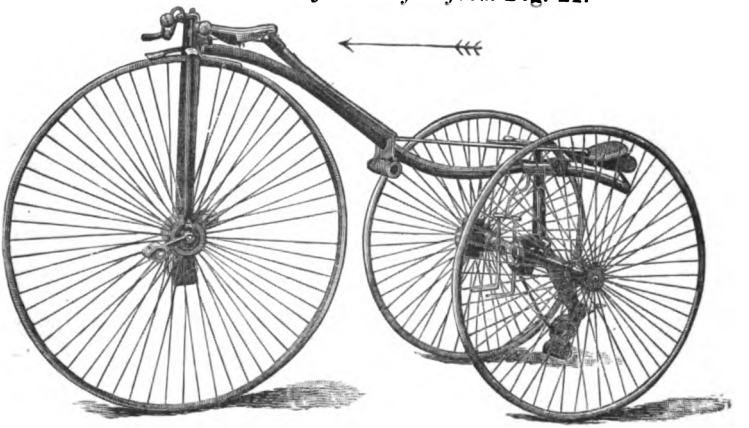
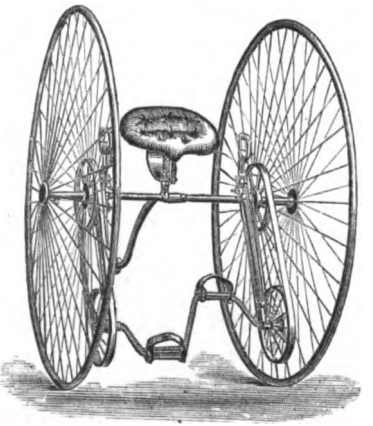


Fig. 23. *Otto Bicycle.*



(*Proceedings Inst. M.E.* 1885.)

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Steering Gear controlled by feet.

Fig. 24.
Longitudinal Section.

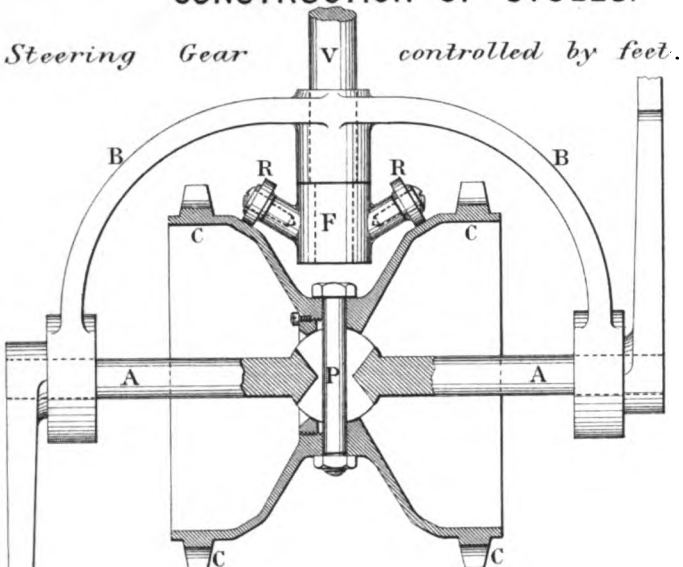
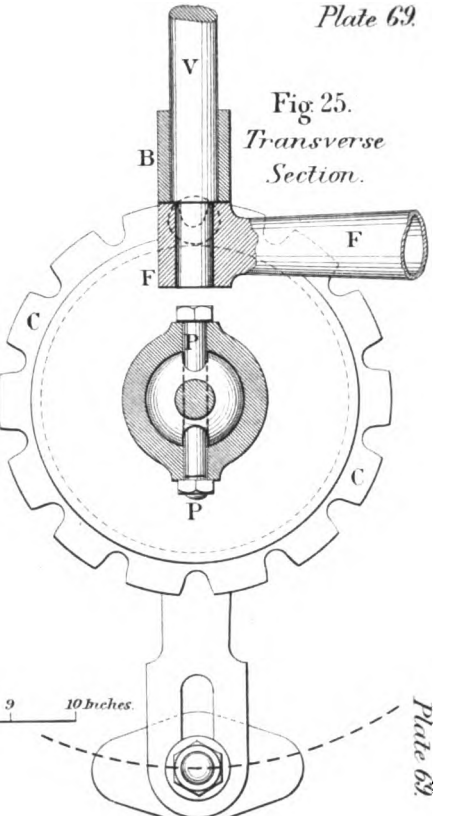
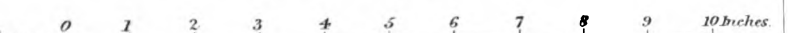
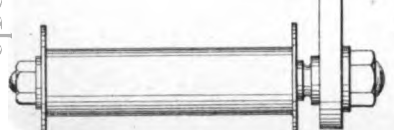


Fig. 25.
Transverse Section.



Scale 1/3rd





(Proceedings Inst. M. E. 1885.)

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Fig. 26. "*Coventry Rotary*" *Tricycle.*

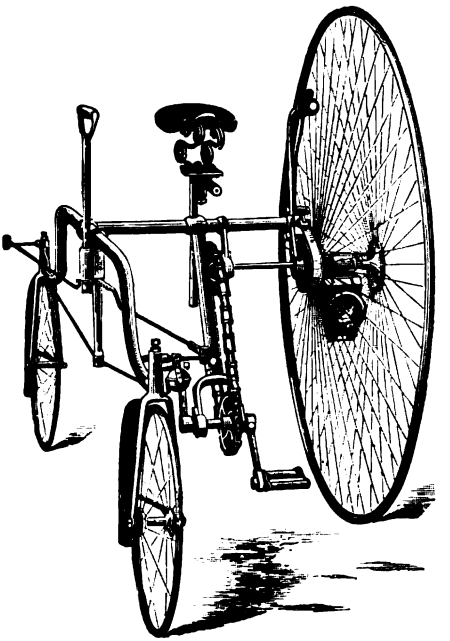
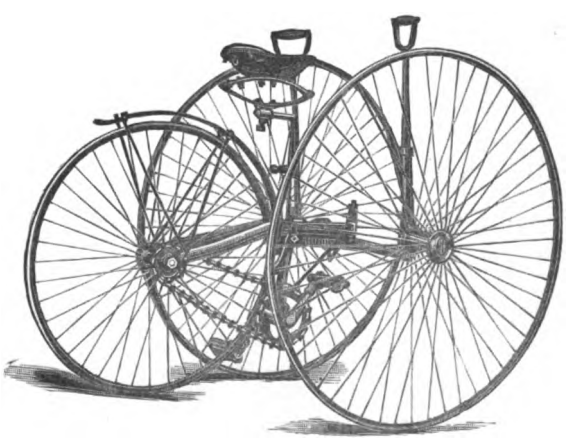


Fig. 27. *Front-steering Tricycle with single driving-wheel.*



(*Proceedings Inst. M.E.* 1885.)

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Fig. 28. *Double driving by Clutch action.*

Scale 1/3rd

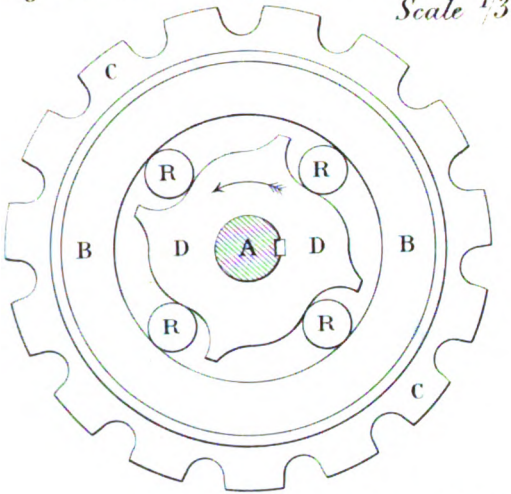
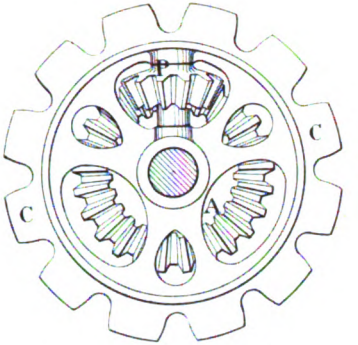


Fig. 29.



Scale 1/3rd

Double driving by Differential Gear.

Section.

Fig. 30.

Scale 1/3rd

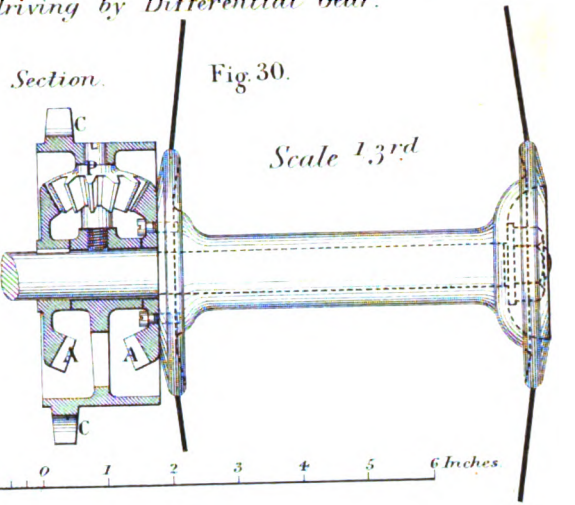


Fig. 31. *Differential Gear for central-geared Tricycles.* *Scale 1/6th*

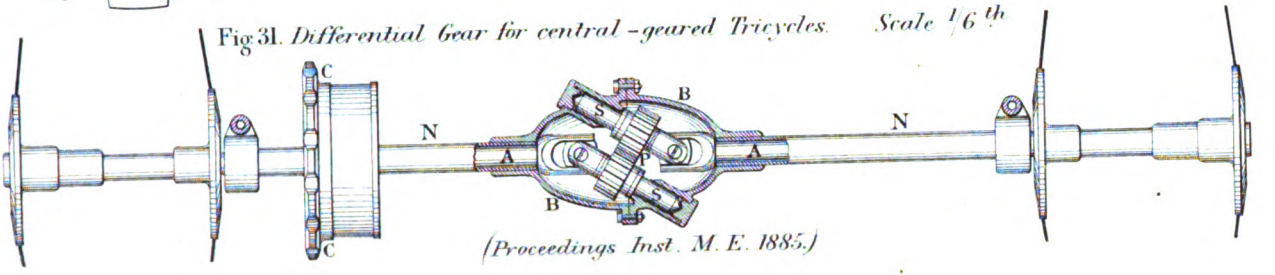


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Plate 71.

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Fig. 32. *Two-track double-driving Tricycle.*

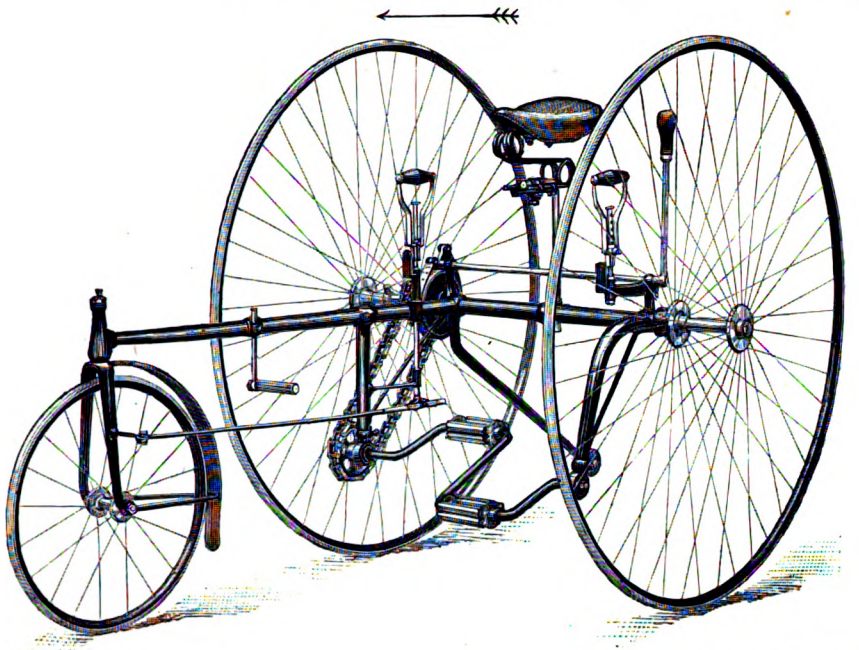

Fig. 33. *Rear-steering Tricycle driven by differential gear.*

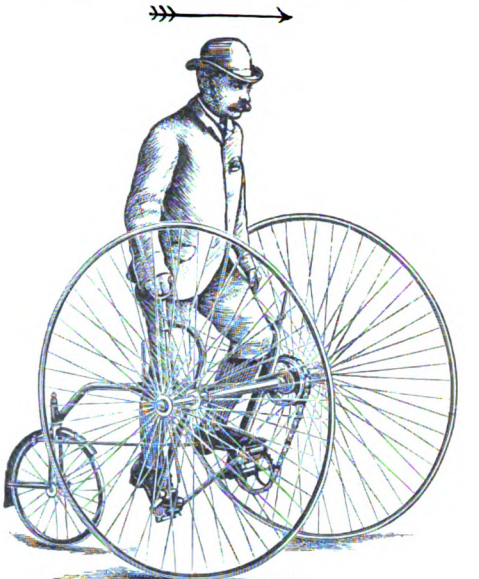

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Plate 72.

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Fig. 34. *Rear-steering Tricycle driven by clutch action.*

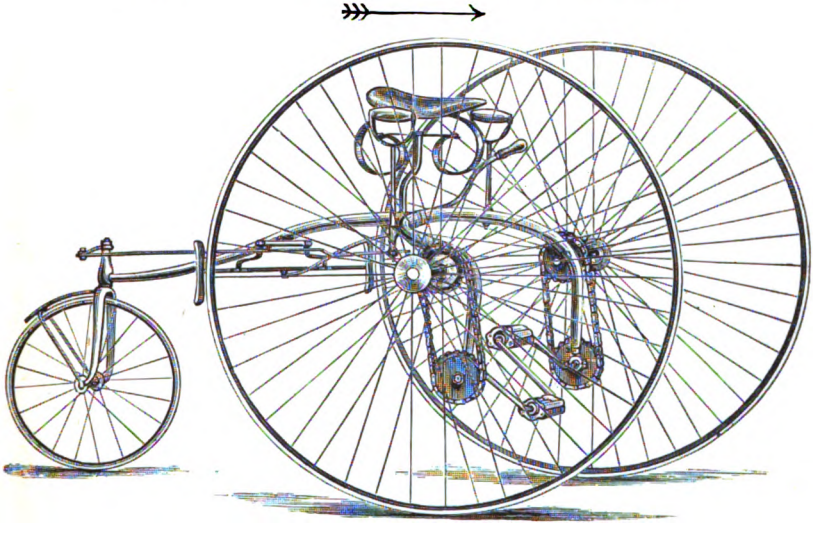
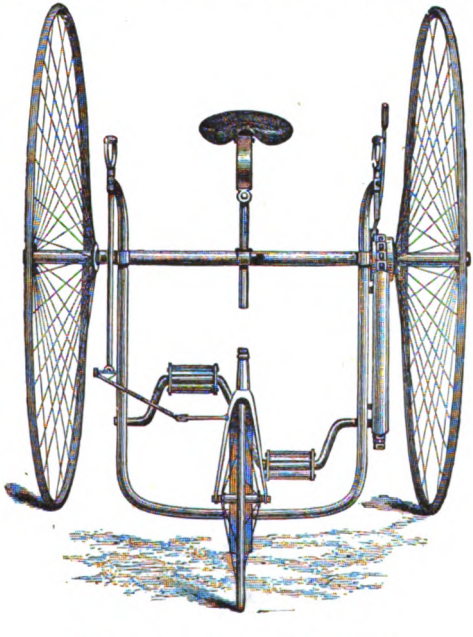


Fig. 35. *Front-steering Tricycle driven by differential gear.*



(*Proceedings Inst. M.E.* 1885.)

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Fig. 36. *Humber Tricycle.*

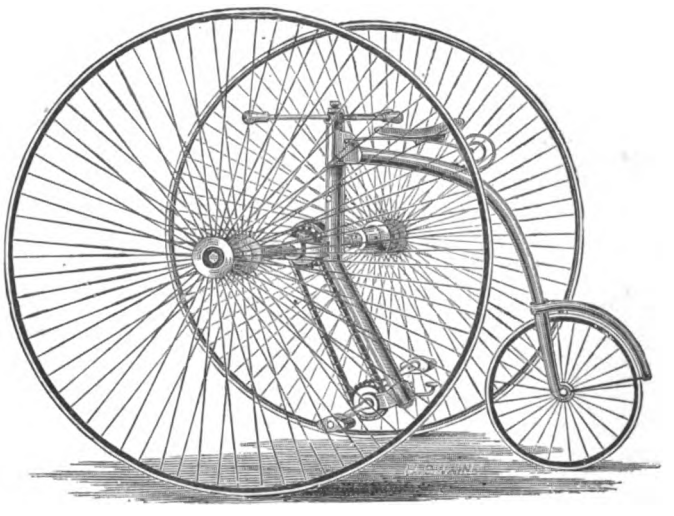
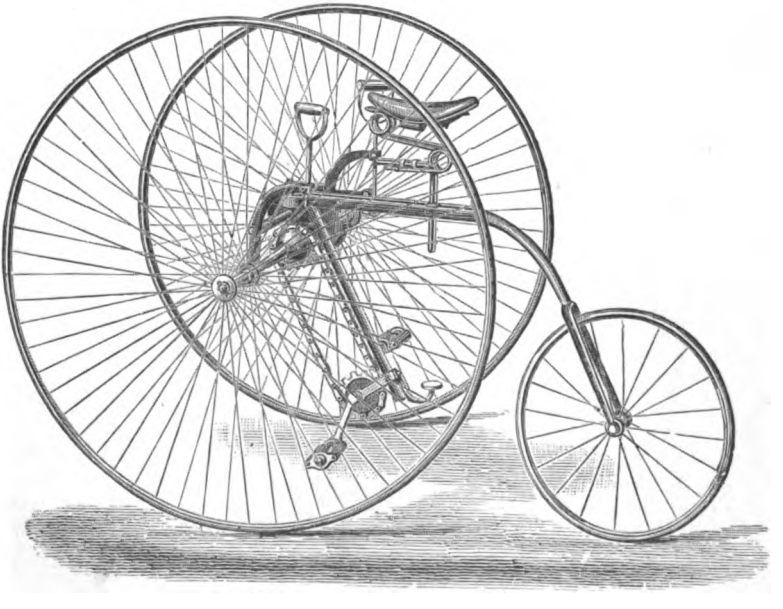


Fig. 37. *Humber Tricycle modified.*



(*Proceedings Inst. M.E.* 1885.)

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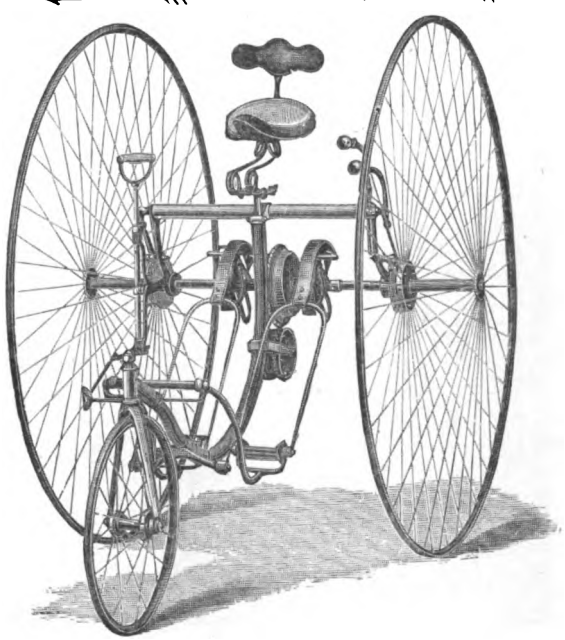
Fig. 38. *Later Humber Tricycle.*

Fig. 39. *Omnicycle.*



(*Proceedings Inst. M.E.* 1885.)

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CONSTRUCTION OF CYCLES.

Expanding Segments of Omnicycle.

Fig. 40.

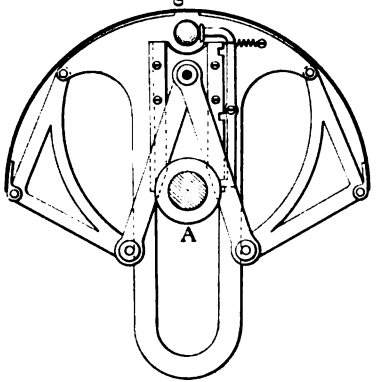


Fig. 41.

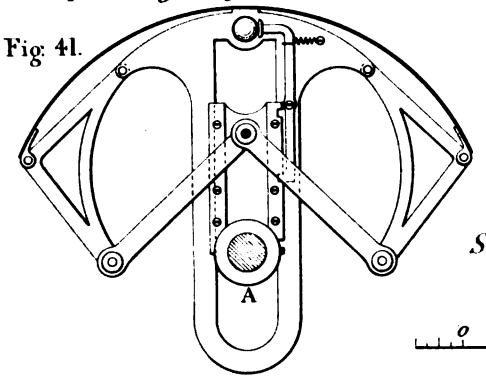
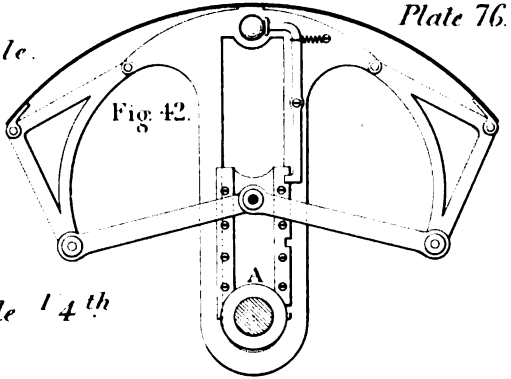


Fig. 42.



Scale 1/4th

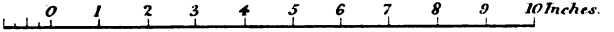
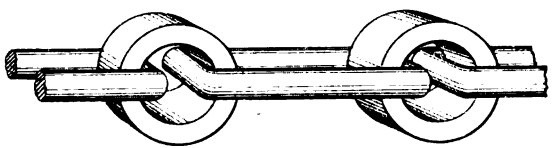


Fig. 43. *Morgan Chain.*
Full size.



(Proceedings Inst. M. E. 1885.)

Fig. 44.

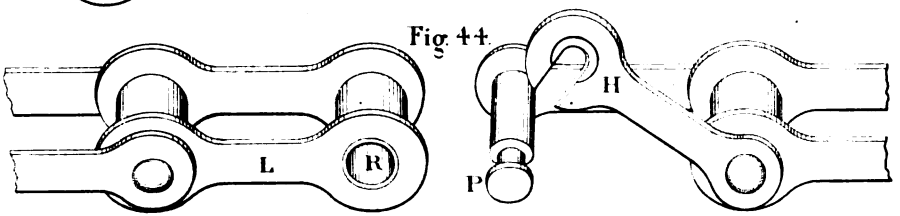


Fig. 45. *Starley's Detachable Link.* *Full size.*

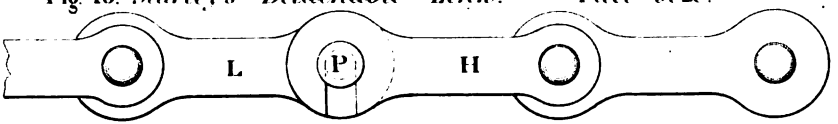


Plate 76.

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Fig. 46. *Simplest Rotary Tricycle.*

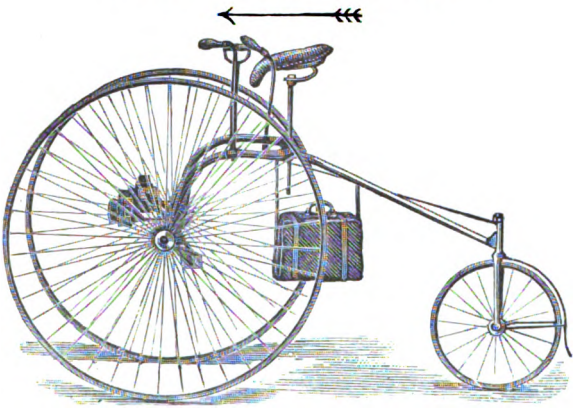
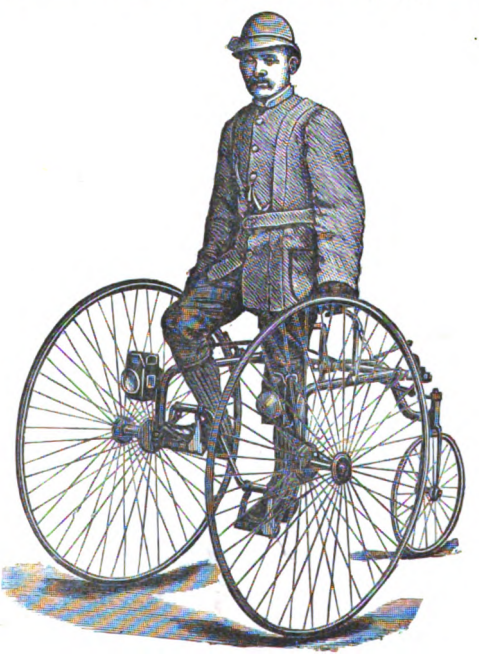


Fig. 47. *Rotary Tricycle with swinging pedals.*



(*Proceedings Inst. M.E.* 1885.)

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Fig. 48. *Driving by Triple Cranks and Coupling-Rods.*

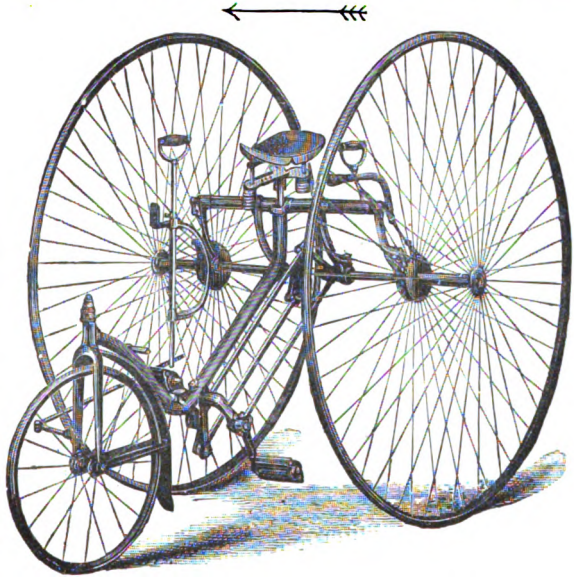
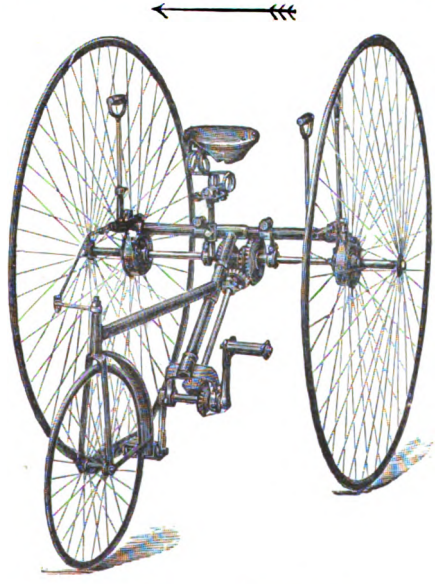


Fig. 49. *Driving through Bevel Gearing.*



(*Proceedings Inst. M.E.* 1885.)

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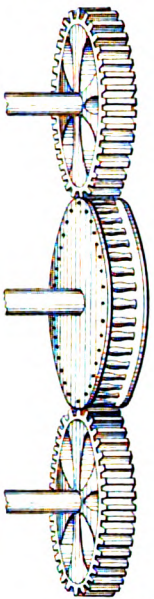
CONSTRUCTION OF CYCLES.

Speed Multiplying Gear.

Fig 50.
Driving through Spur Gearing.



Scale 1/8th

(Proceedings Inst. M.E. 1885.)

Fig 51. *Section.*

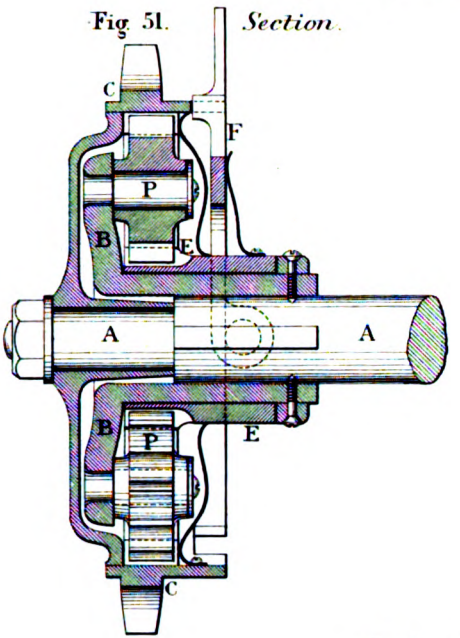
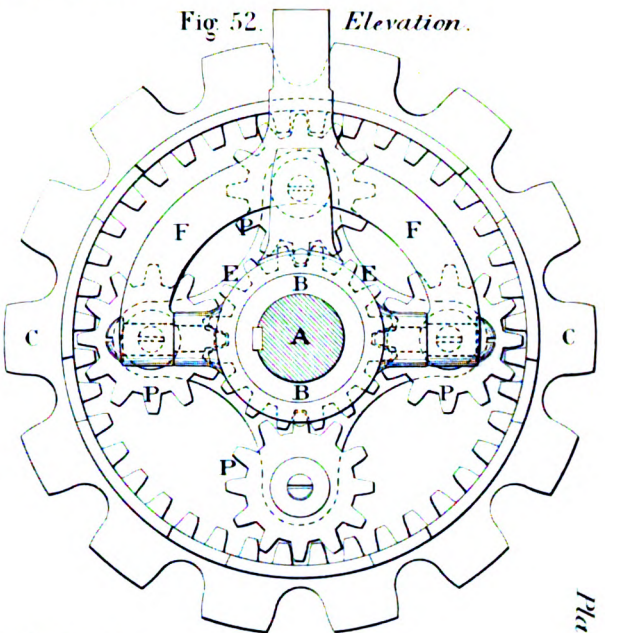


Fig 52. *Elevation.*



Scale half full size.

0 1 2 3 4 5 6 Inches.

Plate 79.

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CONSTRUCTION OF CYCLES.

Crypto-dynamic Power-multiplying Gear.

Scale $^3/_8$ ths

Fig. 54. *Outside View.*

Fig. 55. *Inside View.*

Fig. 56. *Internally toothed Driving Wheel.*

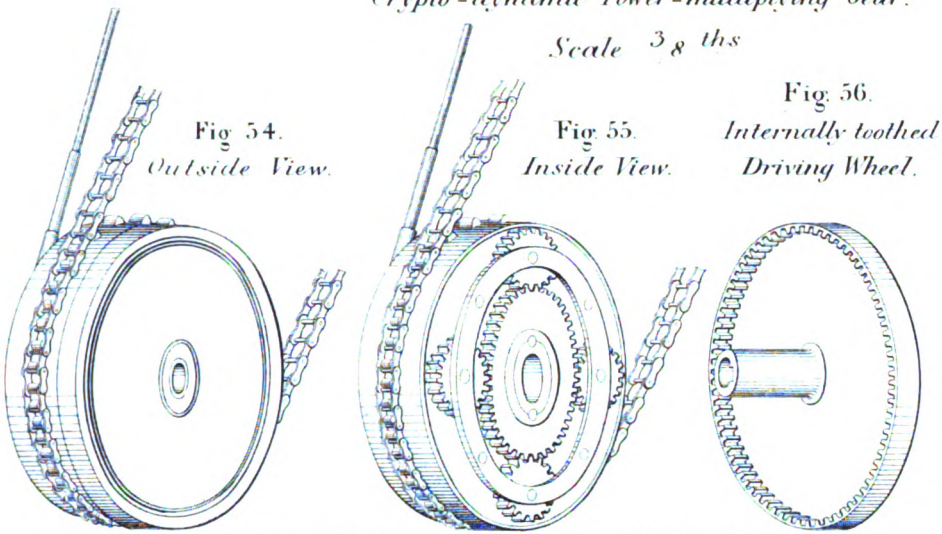
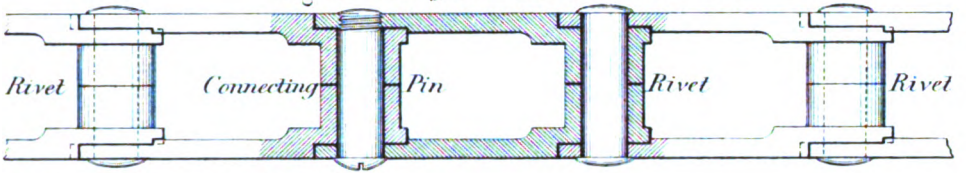


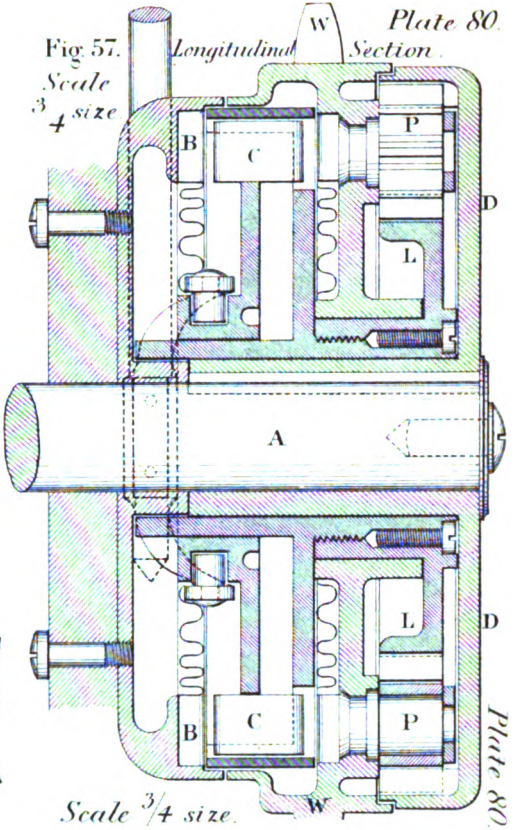
Fig. 53. *Abingdon Chain. Full size*



(Proceedings Inst. M.E. 1885.)

Fig. 57. *Longitudinal Section.* *Scale $^3/_4$ size.*

Plate 80.



Scale $^3/_4$ size.

Plate 80.

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Variable-throw Crank.

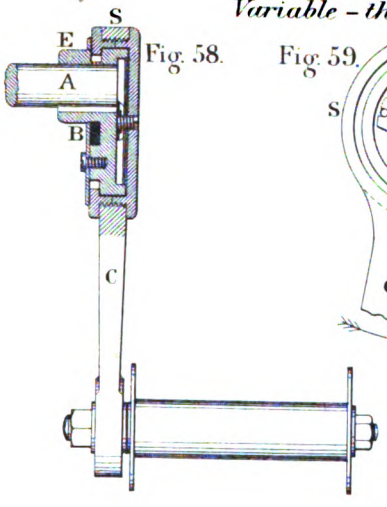

Fig. 58.

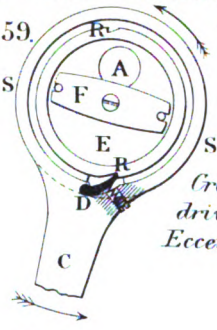

Fig. 59.

Crank driving Eccentric.

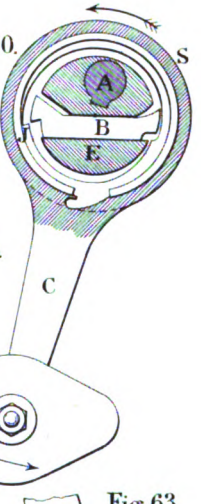

Fig. 60.

Eccentric lifting Crank.

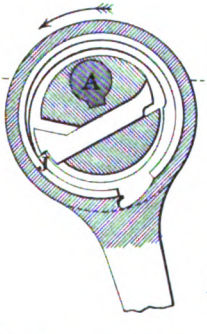

Fig. 61.

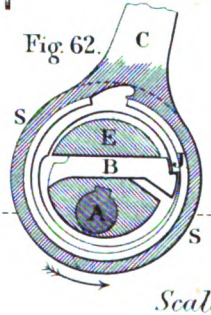

Fig. 62.

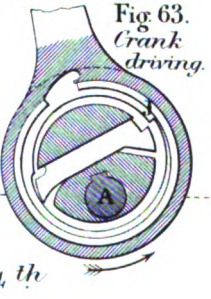

Fig. 63.
Crank driving.

Scale 1/4 th

Crank held stationary; Eccentric revolving for altering throw.

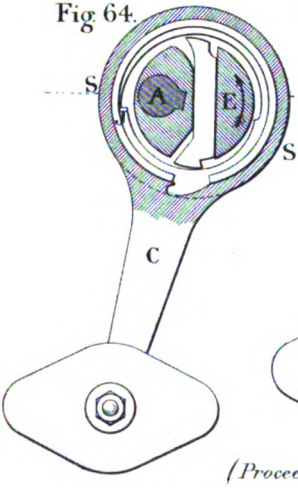

Fig. 64.

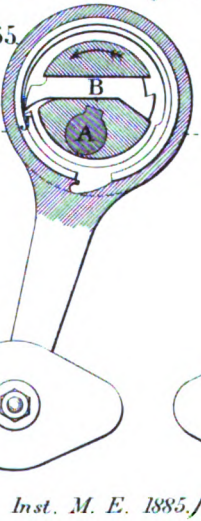

Fig. 65.

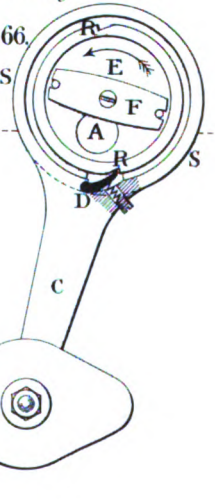

Fig. 66.

(Proceedings Inst. M. E. 1885.)

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Fig. 67. *Devon Tricycle with swing frame.*

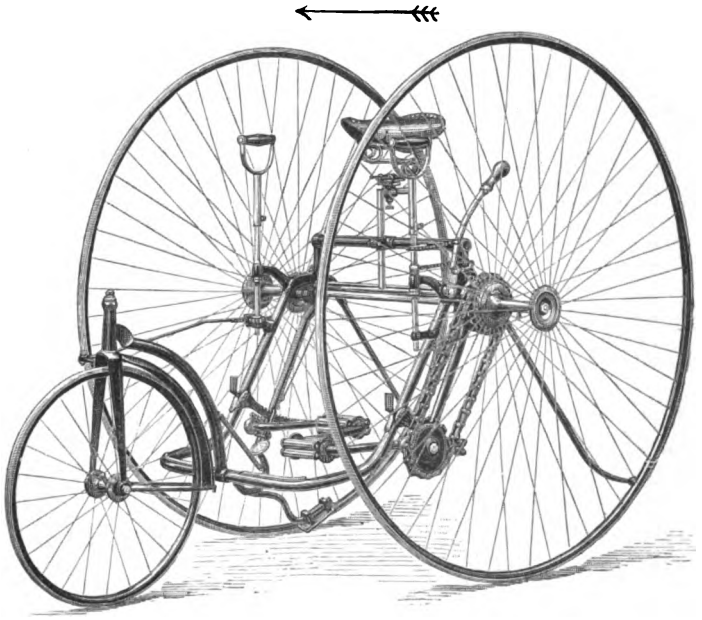


Fig. 68.
Uphill without swing frame.

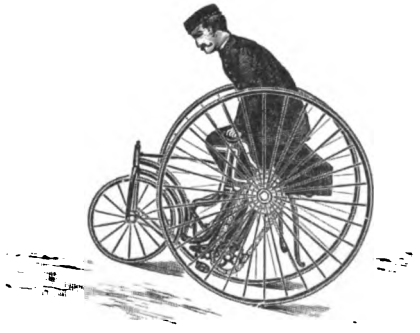
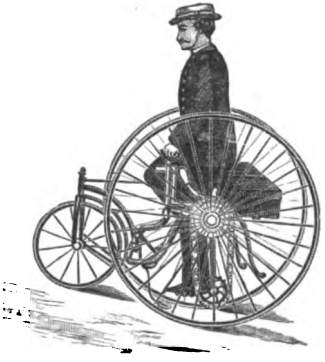


Fig. 69.
Uphill with swing frame.



(*Proceedings Inst. M.E.* 1885.)

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Fig. 70. *Spinaway Tricycle.*

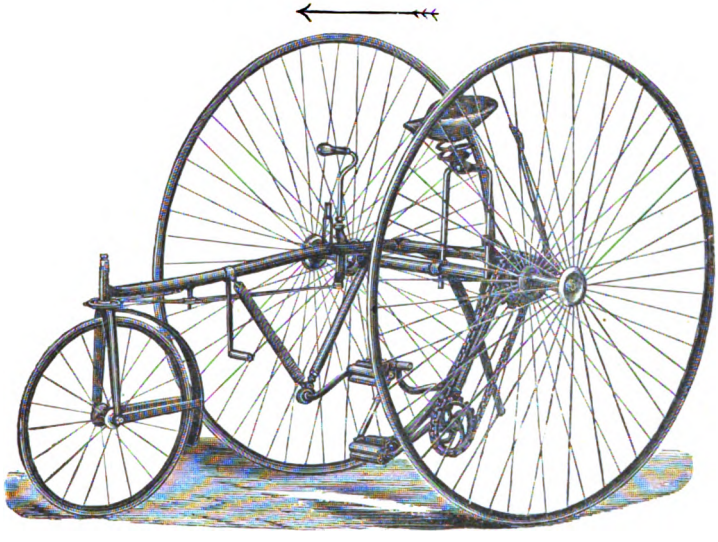
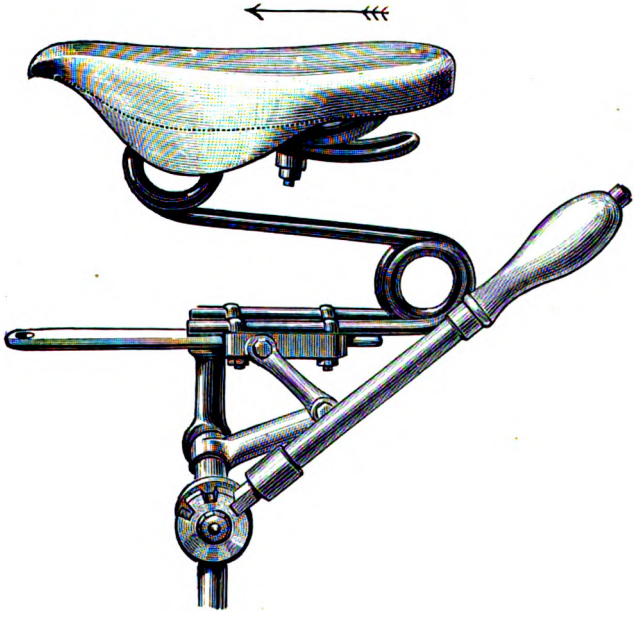


Fig. 71. *Sliding Seat.*



(*Proceedings Inst. M.E.* 1885.)

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Fig. 72. *Velociman Tricycle.*

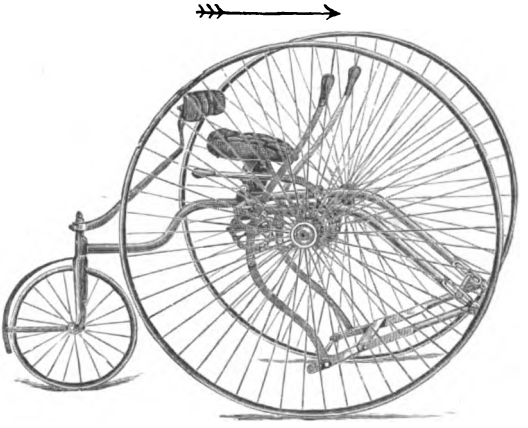

Fig. 73. *Oarsman Tricycle.*

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Fig. 74. *Convertible Sociable Tricycle.*

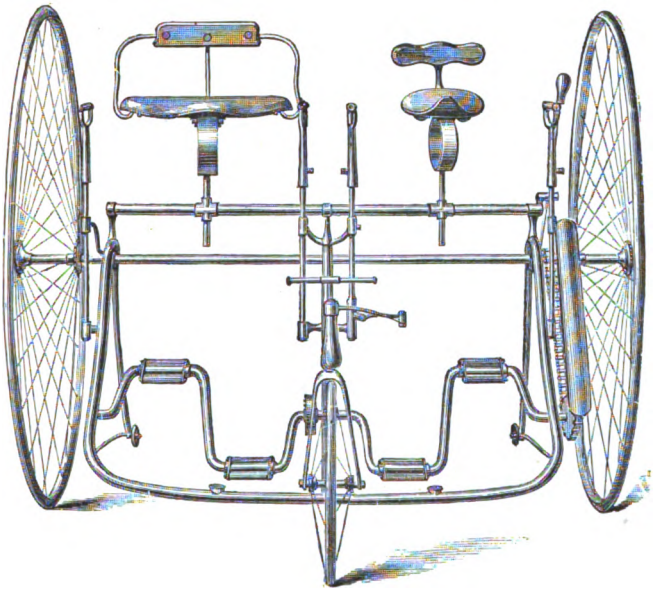
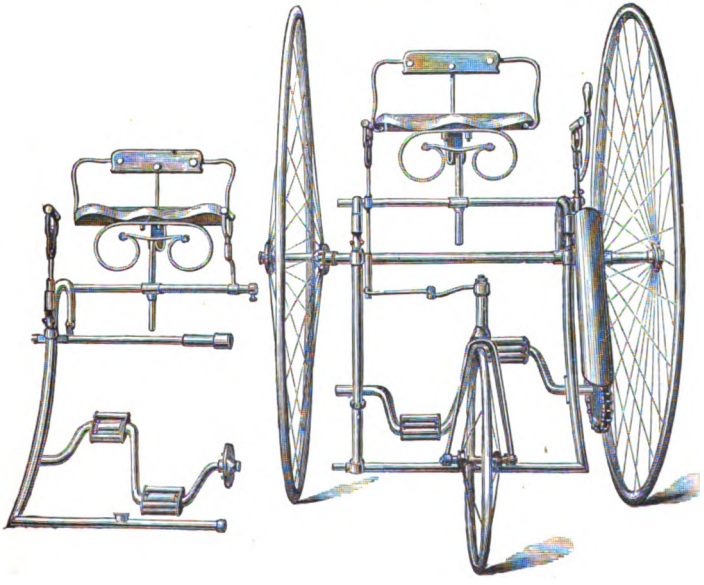


Fig. 75. *Sociable converted into single Tricycle.*



(*Proceedings Inst. M.E.* 1885.)

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Fig. 76. *Sociable Tricyle. Double "Coventry Rotary."*

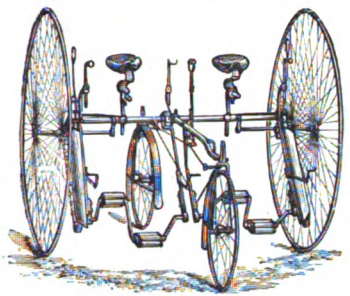


Fig. 77. *"Coventry Rotary" with addition detached.*

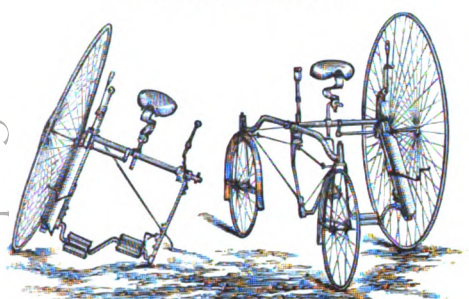
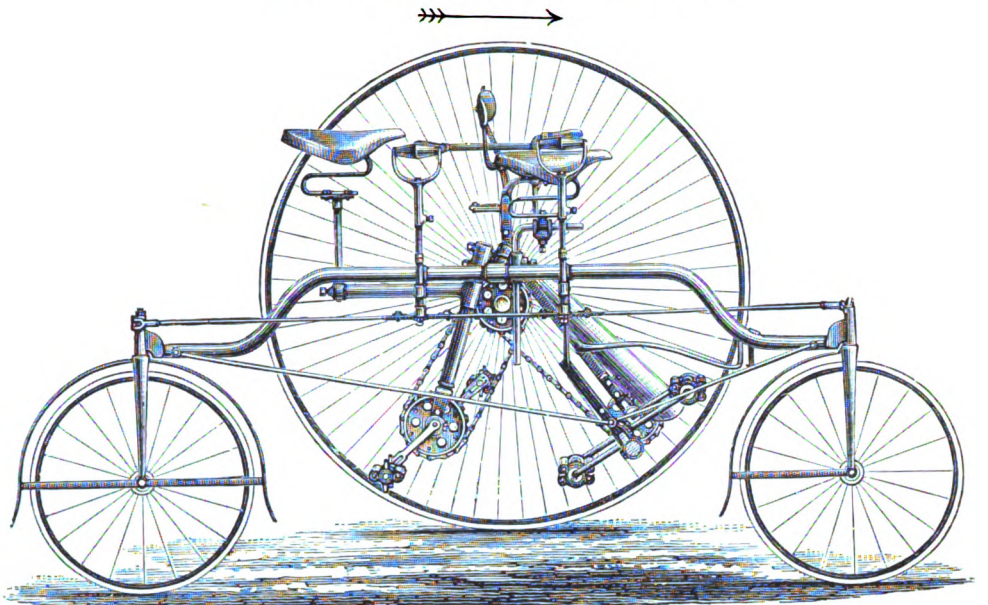


Fig. 78. *"Coventry Rotary" Tandem Tricycle.*



(*Proceedings Inst. M.E.* 1885.)

Pl. 86.

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Fig. 79. *Hinged Coupling Joint for Sociable Tricycles.*

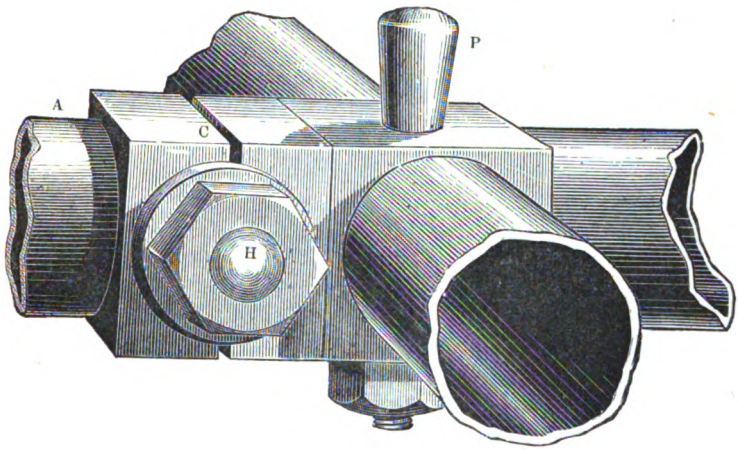
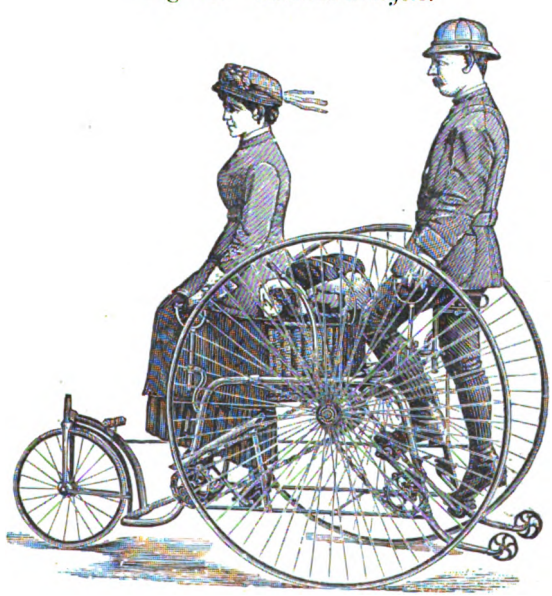


Fig. 80. *Tandem Tricycle.*



(*Proceedings Inst. M.E.* 1885.)

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Fig. 81. *Humber Tandem Tricycle.*

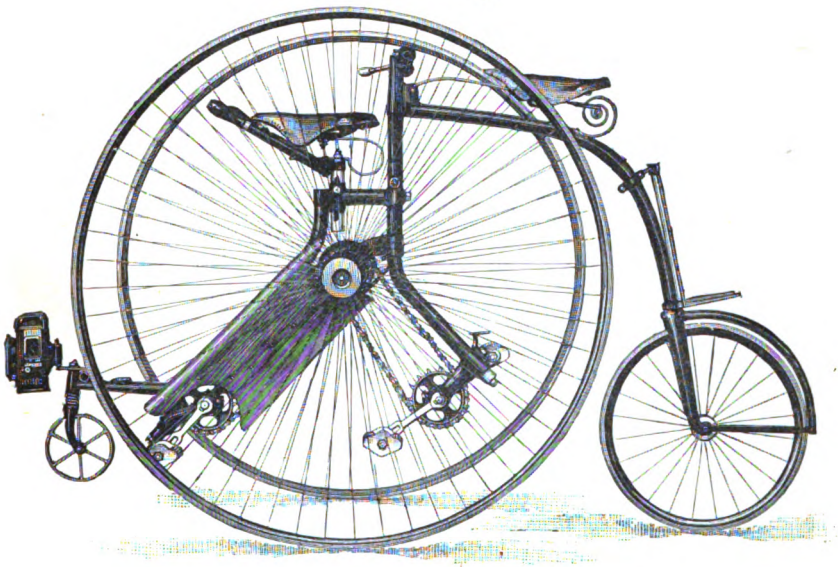
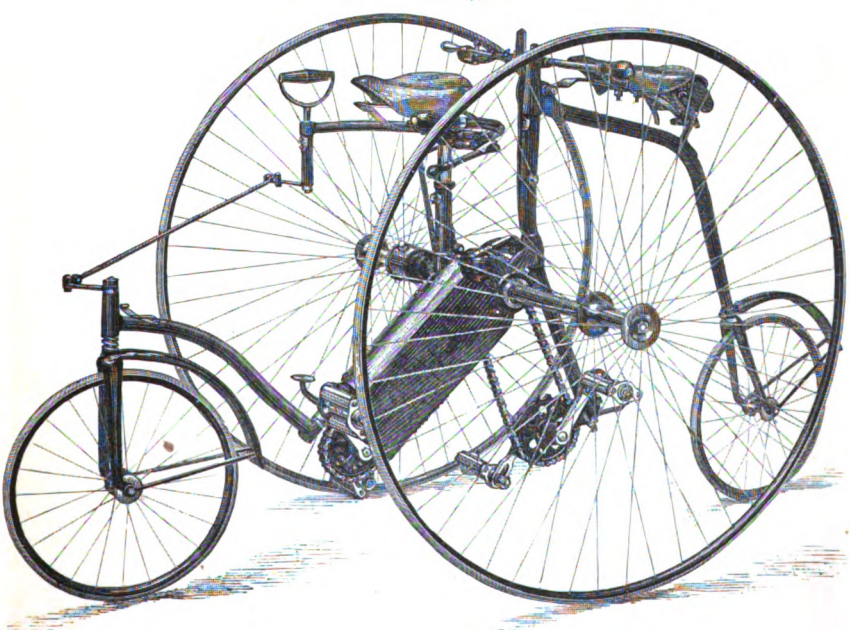


Fig. 82. *Tandem Tricycle with trailing frame.*



(*Proceedings Inst. M.E.* 1885.)

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Fig. 83. *Trailing Frame driving its own wheel.*

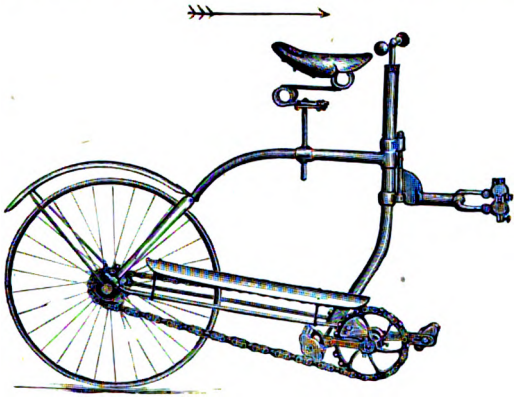
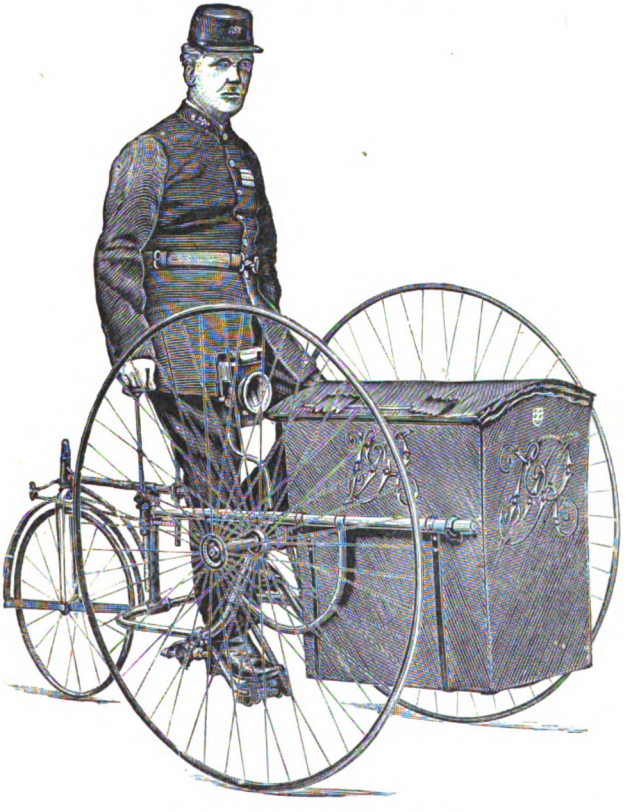


Fig. 84. *Letter Carrier's Carrier.*



(*Proceedings Inst. M.E.* 1885.)

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Fig. 85. *Parcel Post Carrier.*

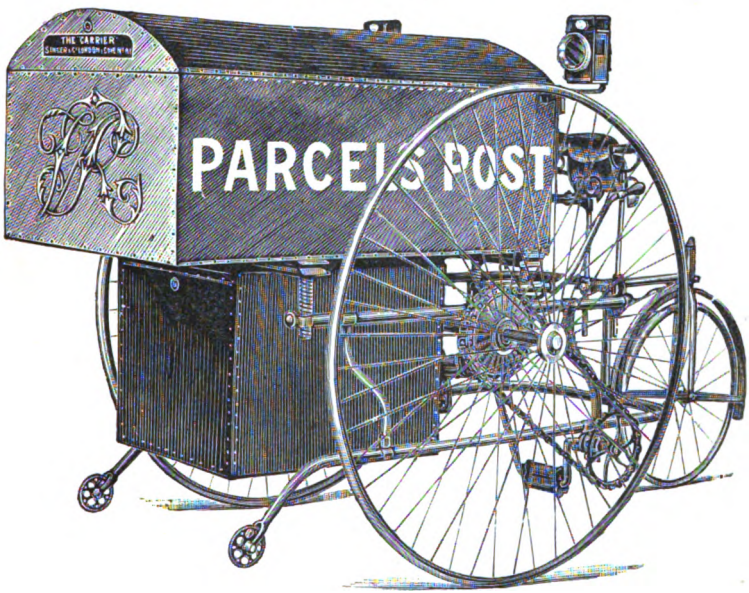
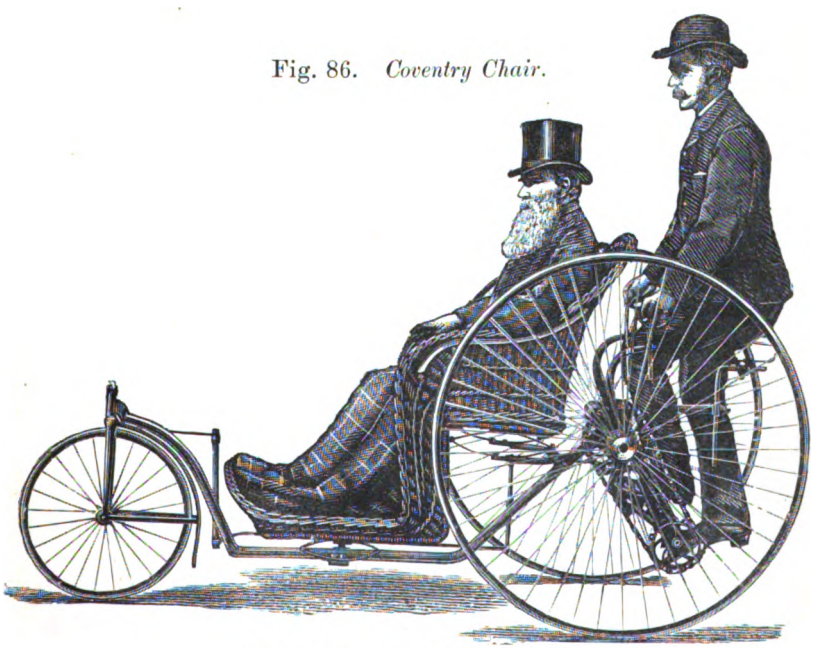


Fig. 86. *Coventry Chair.*



(*Proceedings Inst. M.E.* 1885.)

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Fig. 87. *Newspaper Carrier.*

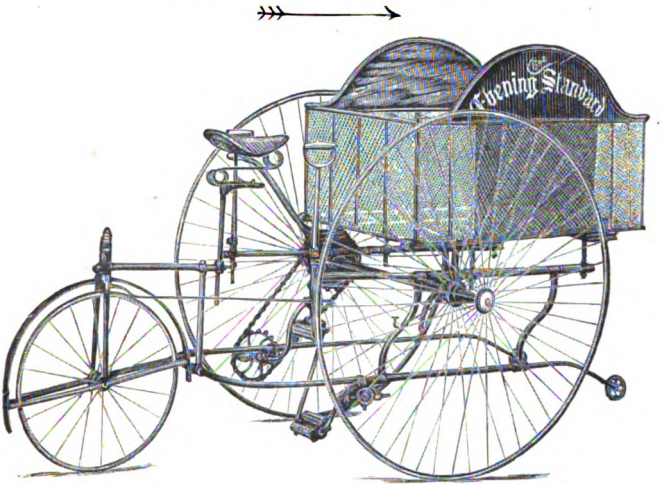
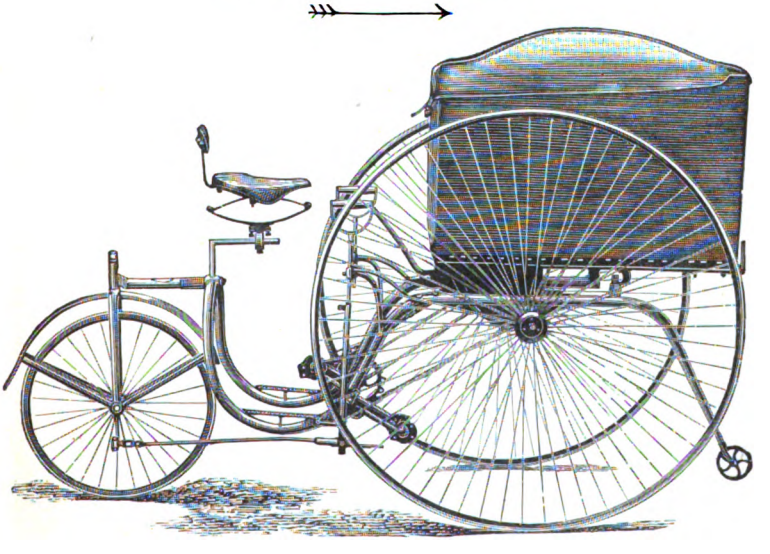


Fig. 88. *Tradesman's Carrier.*



(*Proceedings Inst. M.E.* 1885.)

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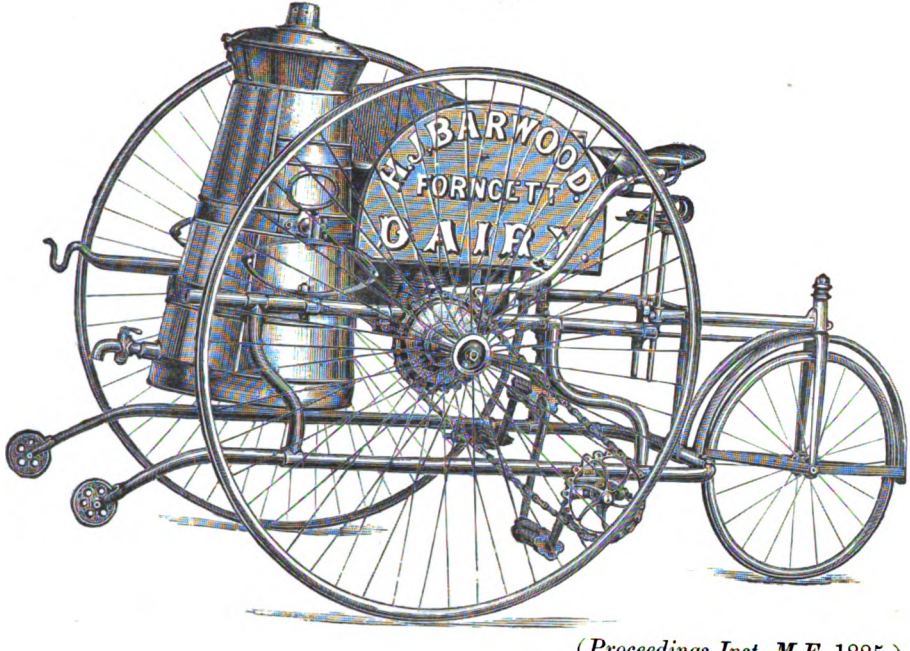
Fig. 89. *Milk Carrier.*



(*Proceedings Inst. M.E.* 1885.)

Fig. 90. *Single spoke Tangential Wheel.*

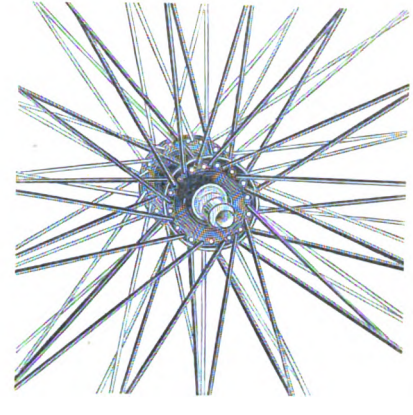


Plate 92.

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Fig. 91. *Central-driving and Side-geared Tricycle with* T *frame and Bicycle steering.*

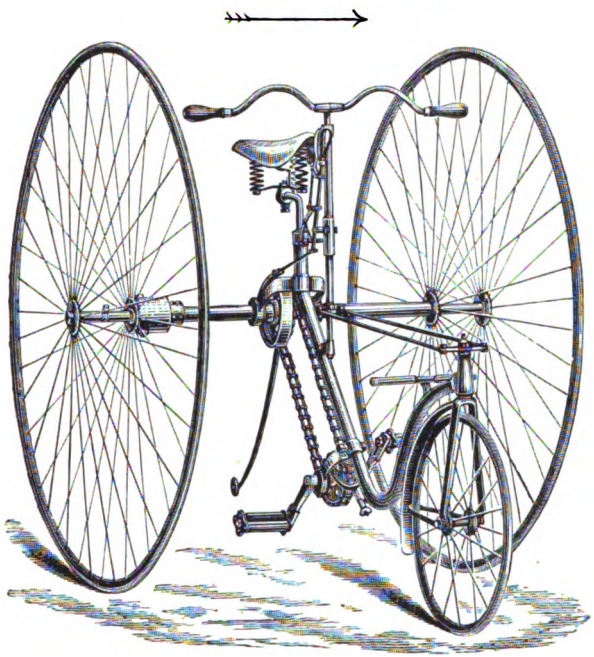
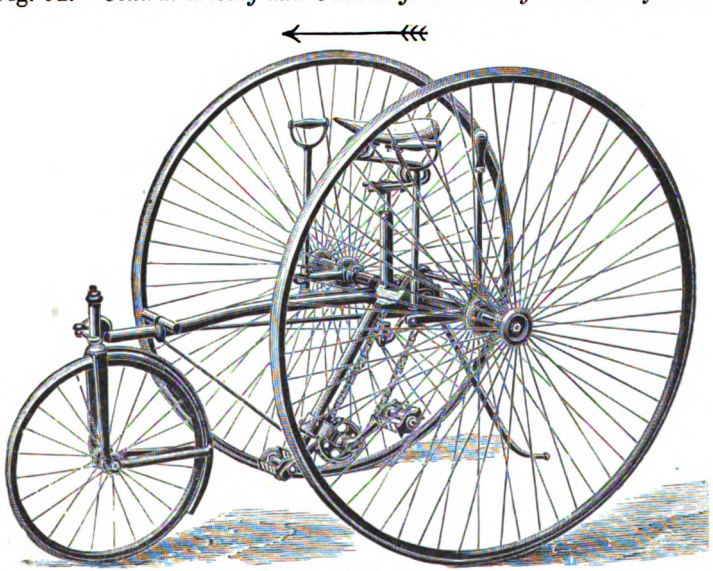


Fig. 92. *Central-driving and Central-geared Tricycle with* T *frame.*



(*Proceedings Inst. M.E.* 1885.)

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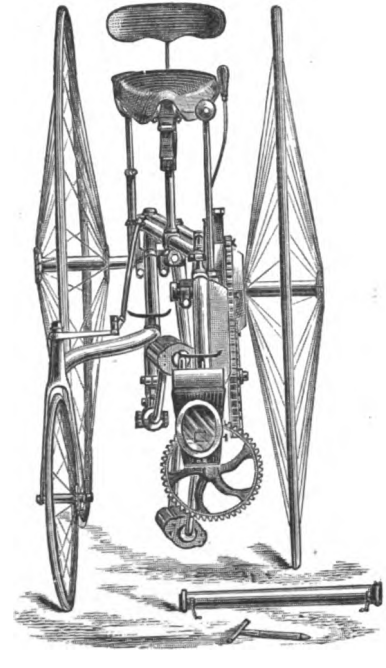
Fig. 93. *Tricycle with folding frame.*

Fig. 94. *Tricycle folded up.*



(*Proceedings Inst. M.E.* 1885.)

Plate 94.

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CONSTRUCTION OF CYCLES.

Telescopic Axle

Scale 1/5th

Fig. 95.

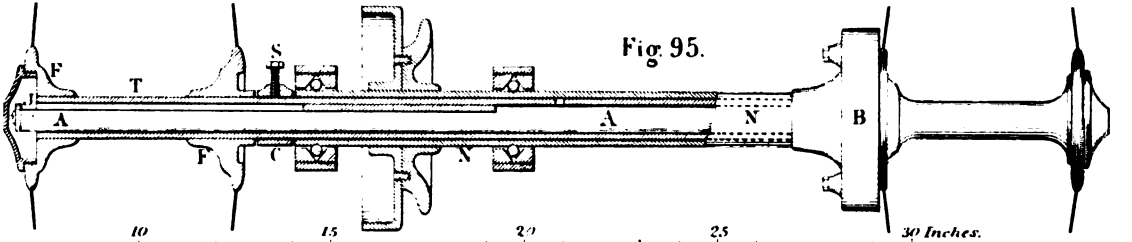


Fig. 96

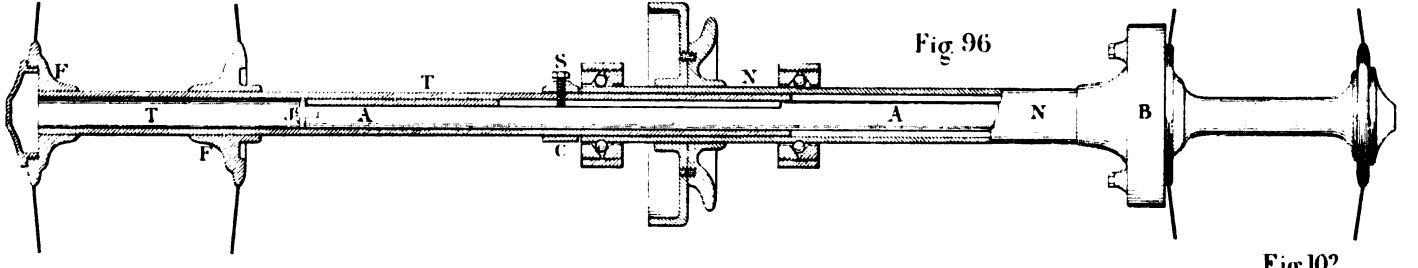


Fig. 97.

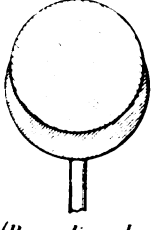


Fig. 98.

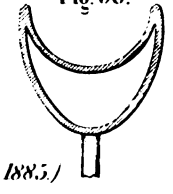


Fig. 99.

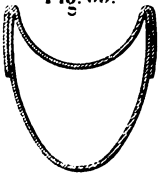
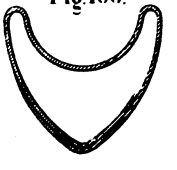


Fig. 100.



Sections of Wheel Rims. Full size.

Fig. 101.

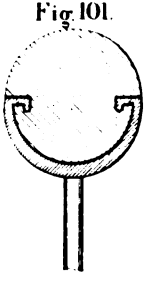
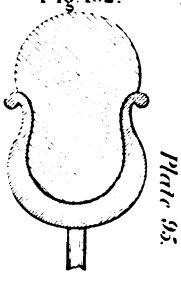


Fig. 102.



(Proceedings Inst. M.E. 1885.)

Plate 95.

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Æolus Ball Bearing. Half full size.

Fig. 103.

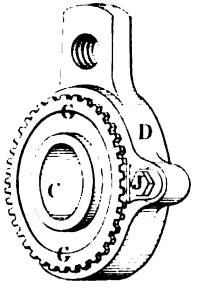


Fig. 104.

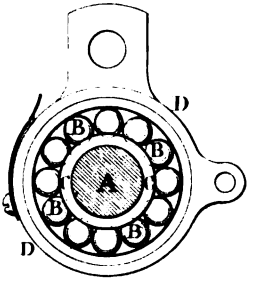


Fig. 105.

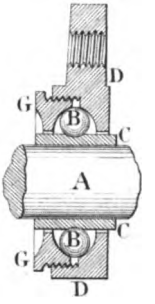
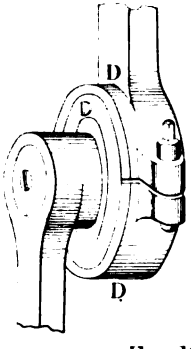


Fig. 106.



Ball Bearing. *Half full size.*

Fig. 107.

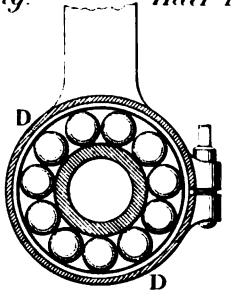


Fig. 108.

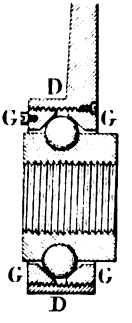
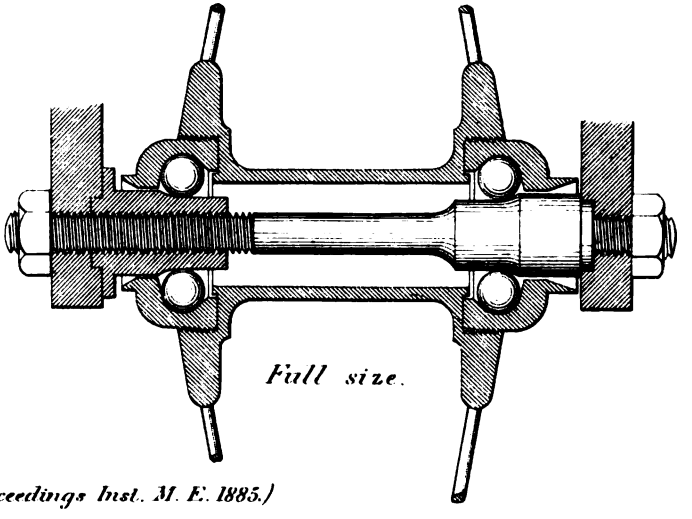


Fig. 109. *Ball Bearings for small wheels.*



Full size.

(Proceedings Inst. M. E. 1885.)

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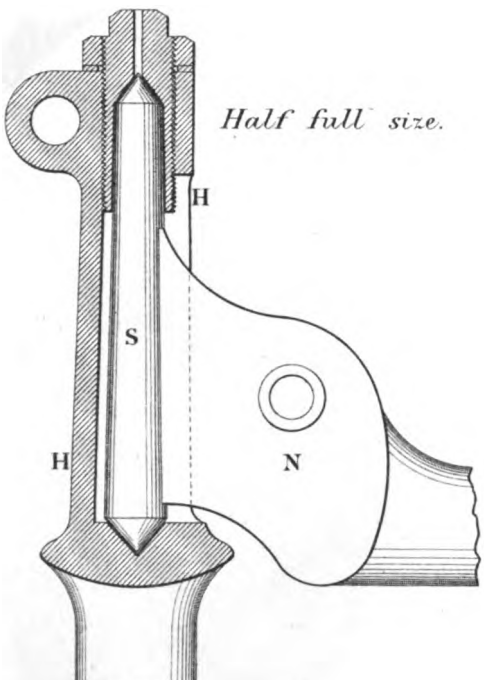
Fig. 110. *Stanley Head.*



(Proceedings Inst. M.E. 1885.)

Fig. 111. *With Ball Bearings.*

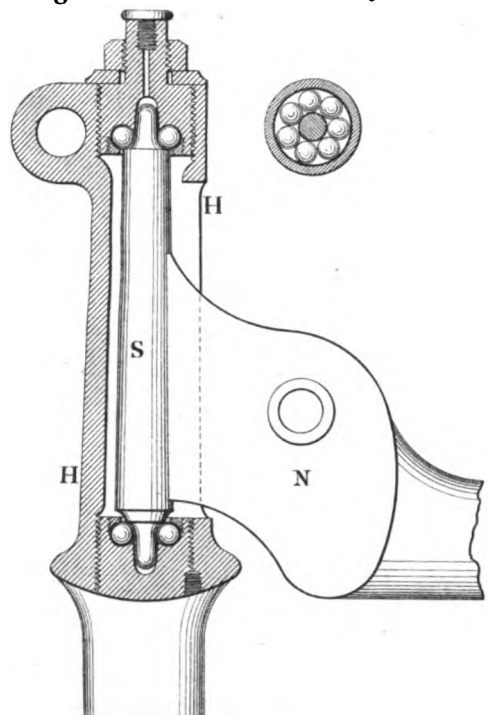


Fig. 112. *With Central Pin.*

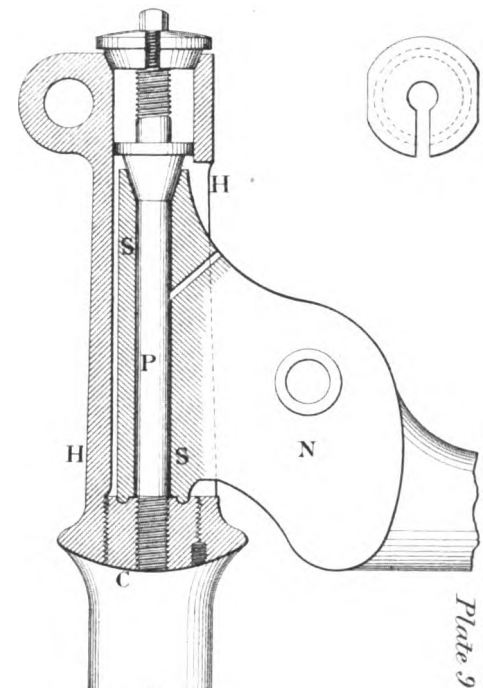


Plate 97.

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Fig. 113. *Quadrant-steering Tricycle.*

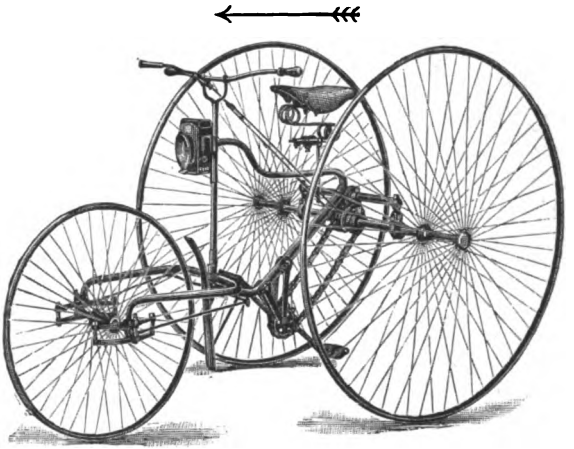
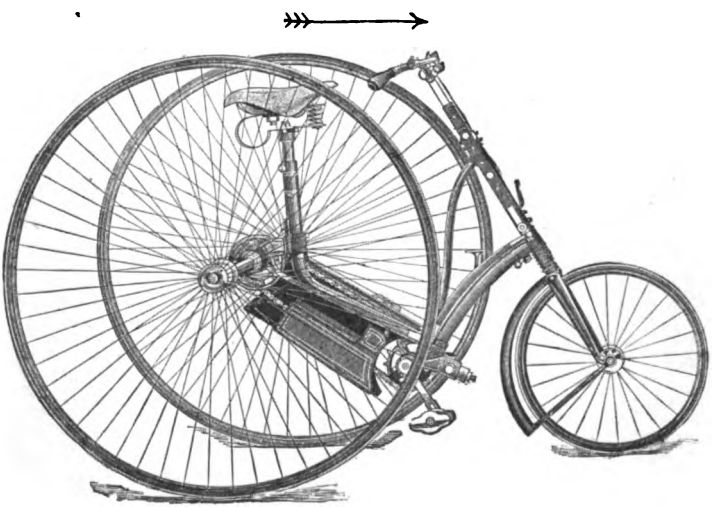


Fig. 114. *Humber Tricycle with automatic bicycle-steering.*



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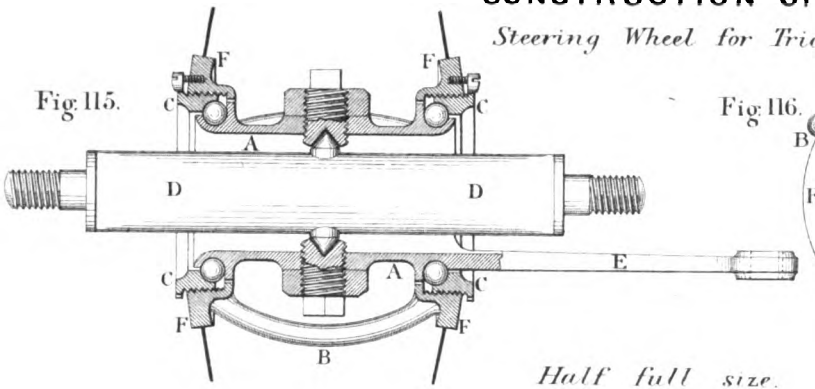
Steering Wheel for Tricycles.

Fig. 115.



Half full size.

Fig. 116.

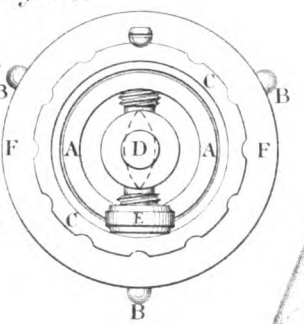


Fig. 118. *Foot-brake.*

Scale 1/4th

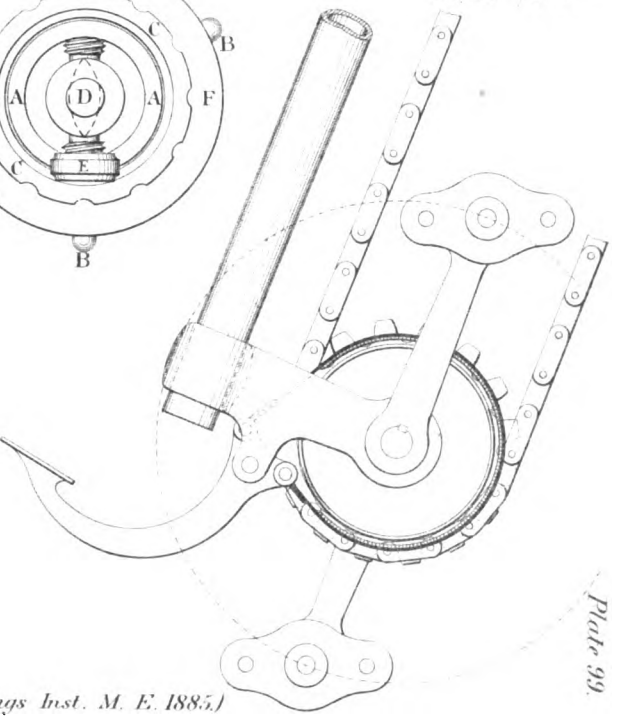
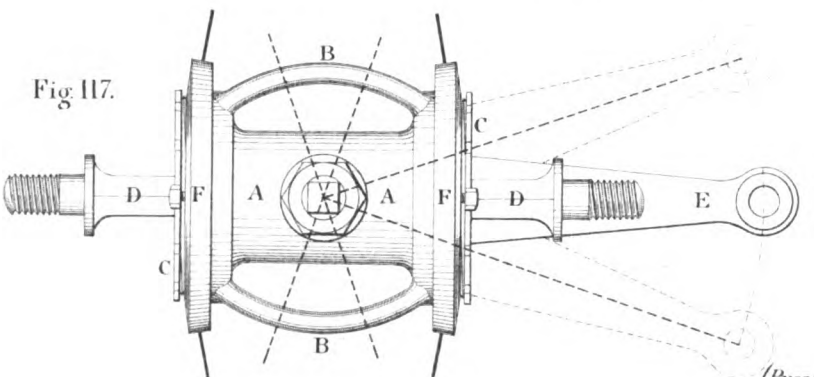


Fig. 117.



(Proceedings Inst. M. E. 1885.)

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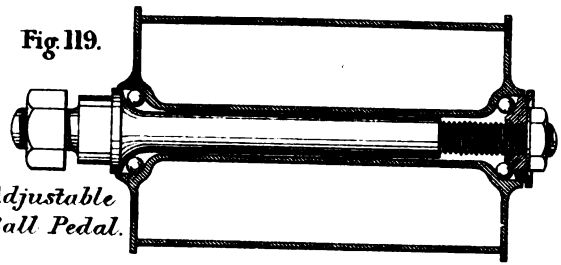
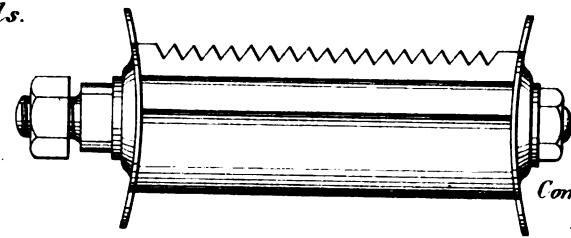
Fig. 119.



Adjustable Ball Pedal.

Pedals.

Fig. 120.

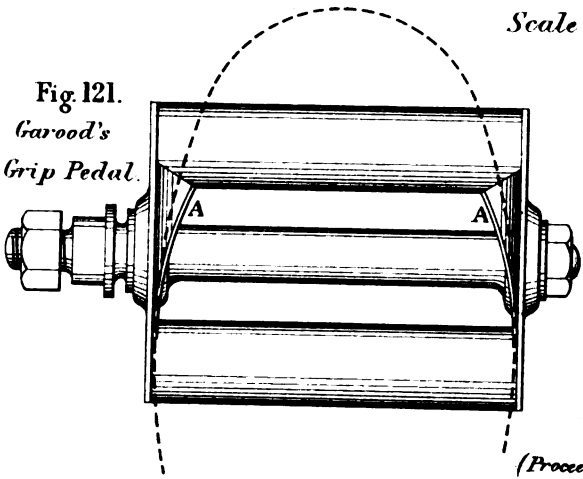


Combination Pedal.

Scale half full size.

Fig. 121.

Garood's Grip Pedal.



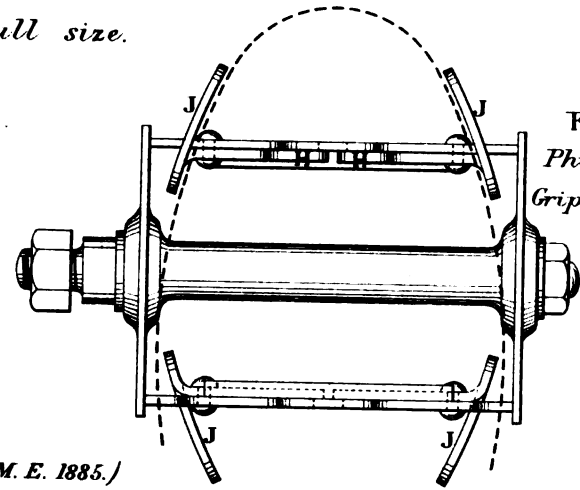


Fig. 122.

Phillips' Grip Pedal.

(Proceedings Inst. M. E. 1885.)

Plate 100.

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ON THE CONSTRUCTION OF MODERN CYCLES.

By Mr. ROBT. ED. PHILLIPS, of London.

The Cycle industry in this country has grown with such rapidity, and has already assumed proportions of such magnitude, as to lead the author to hope that the present paper may prove of some interest to the Institution. It would not be possible within any reasonable limits to do justice to all matters connected with cycles; and he therefore purposes dealing only with their general construction: pointing out the underlying principles, and describing the various types at present made, in order to show how far these principles have been carried out, and what degree of perfection has already been attained.

Bicycle.—The invention of the Bicycle is universally accredited to Gavin Dalzell, a cooper by trade, living at Lesmahagow in Lanarkshire, who in 1836 first fixed a pair of cranks to one of the wheels of a machine similar to a "hobby horse," a vehicle which was constructed with two small wheels mounted to run in a line one before the other, and across which the rider straddled, propelling himself from the ground by his feet on either side; the addition of the cranks converted it into a bicycle. It was driven by working with the feet pendulum levers hung on the front part of the frame and connected by coupling rods to the cranks, which were fixed on the axle of the rear wheel. At a later period the cranks were placed on the axle of the front wheel, which then became the driving as well as the steering wheel; and the rider worked direct on the cranks, without the intervention of levers. Owing to its crude construction this machine was rightly termed a "bone-shaker;" and it underwent no real improvement until the introduction of the "suspension" wheel, from which may be said to have sprung

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the modern cycle. To whom the invention of the suspension wheel is to be ascribed is somewhat uncertain; but circumstances go to show that it is due to a Past-President of this Institution, Mr. Cowper, inasmuch as in 1868, before suspension wheels were made in this country, certain improvements in velocipedes were specified by him, which cover amongst other things the suspension wheel with wire spokes, hollow felloes, and rubber tyres, and also anti-friction roller-bearings. Without these features or some modifications of them, no cycle at the present day is satisfactory.

Tricycle.—Although the Tricycle, or as it was called in early days the velocipede, was invented contemporaneously with the bicycle, it did not attract the same attention that was accorded to the bicycle until some six years later. Doubtless the perfection to which, by a slow but sure development, the narrow-gauge machine or bicycle had during that time been brought, encouraged manufacturers and others to turn their attention to the broad-gauge machine or tricycle.

Statistics.—The extent to which inventors have applied themselves to perfecting both kinds of cycles may be inferred from the fact that over a thousand patents for improvements relating to velocipedes had been applied for down to the end of 1883; whilst during the year 1884, at the commencement of which the new patent act came into force, no less than 637 applications were filed. The dimensions to which the manufacture of bicycles has grown may be gathered from the fact that there are now upwards of 170 firms who devote themselves exclusively to it, and who produce over five hundred different machines; and it is calculated that in Coventry alone, the seat of this industry, it employs three thousand men, and throughout the United Kingdom five thousand at least. The number of machines sold annually is estimated at 40,000; reckoning their average price at £20 each, a gross amount of £800,000 is attained. The capital invested in the manufacture is roughly computed at £900,000. Considering the prejudices that had to be overcome in introducing cycles, and the risks that had to be incurred in embarking capital in a manufacture which few thought at the time was dependent upon anything more than a passing fancy, it must be allowed that a wonderful advance has been made in so short a period.

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Performances.—A few of the most remarkable performances by which public notice has been attracted to cycles are here recorded, being given in tabulated form for convenience of comparison:—

Performance of Cycles on a special path for Racing.

Distance run. Miles.	Duration of Race, hours.		Mean Speed, miles per hour.	
	Bicycle.	Tricycle.	Bicycle.	Tricycle.
1	0·044	0·050	22·6	20·0
5	0·238	0·272	21·0	18·4.
10	0·489	0·543	20·5	18·4
20	0·985	1·145	20·3	17·5
25	1·278	1·442	19·6	17·3
50	2·733	3·054	18·3	16·4
100	5·835	6·726	17·1	14·9

Performance of Cycles on ordinary roads.

Nature of Journey.	Bicycle. Hours. Days.	Tricycle. Hours. Days.
Distance of 100 miles	7·19	7·58
Land's End to John O'Groat's, about 900 miles	160·17 = 6·67	197·33 = 8·22
Land's End to John O'Groat's and back, and thence to London, about 2050 miles .	456 = 19	
Greatest Distance travelled in 24 hours .	266¼ miles.	231½ miles.
Mean Speed for the 24 hours, miles per hour .	11·1 miles.	9·6 miles.

From these performances it appears that, whether in short or long races, a bicycle has the advantage in speed over a tricycle to the extent of 2 to 2½ miles per hour; while as the length of the race increases from 1 mile up to 100 miles, the mean speed of both machines alike falls off by the amount of 5 to 5½ miles per hour.

Classification.—The large variety of cycles may be classified as follows:—

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Bicycles.

1. Bicycles of the ordinary type.
2. Safety bicycles, which may be subdivided into
   a. Dwarf bicycles with geared rotary action.
   b. Dwarf bicycles with lever action.
   c. Safety bicycles with steering wheel in front.
3. Tandem bicycles.
4. Otto bicycle.

Tricycles.

1. Single Drivers, which may be subdivided into
   a. Rear steerers.
   b. Coventry Rotary, side steerer.
   c. Double front steerers.
2. Double Drivers, which may be subdivided into
   a. Those driving by clutch action.
   b. Those driving by differential gear.
3. Humber tricycle.
4. Hand-power tricycles.
5. Sociables.
6. Tandems.
7. Carriers.

All these tricycles may be again subdivided as driven by "rotary" or by "lever" action, like the bicycles.

Any particular make of machine mentioned in this paper will be referred to only in a typical sense, without implying that it is better than others, the author's position being a neutral one, as he is not connected with any firm engaged in the manufacture of cycles.

Bicycles.

Ordinary Bicycles. — The ordinary type of bicycle illustrated by Fig. 1, Plate 61, is so familiar that it need not be referred to at any length, as the special details of its construction will be dealt with later on. As regards its balance, anything supported on only two points is not stable, and will fall to one side or the other. In a bicycle one of the two points, which are the two wheels, is capable of being turned sideways, constituting when in motion an act of recovery, because by turning the wheel to the side towards which the machine is falling the balance is recovered;

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and equilibrium is maintained by continually turning the wheel towards one side or the other. As the rider is seated only a little behind the centre of the driving wheel, he is able by means of his feet alone to control the steering and so to maintain his balance, the cranks forming levers by which he is able to turn the driving wheel as required to either side. Owing to this action he must, when exerting any power, pull at the handle-bar with his arms alternately on the one side and on the other, in order to counteract the thrust of his feet on the cranks; otherwise the machine would be turning first to one side and then to the other. It is this combined action which renders the riding of a bicycle so difficult to learn. Theoretically it is impossible to ride a bicycle in a perfectly straight line except at a very high speed, and then only for a short distance when no power is being exerted to drive it. As soon as the freedom to deviate from the straight line is removed, the balance is destroyed, and the rider is compelled to dismount; for instance, if the wheels get into the groove of a tram rail, or if the steering head becomes locked, in either case the bicycle is prevented from being steered, and can no longer be ridden.

Weight.—The weight of the ordinary roadster bicycle varies from as many lbs. as there are inches in the diameter of the driving wheel, down to from 15 to 20 lbs. less than the weight corresponding with 1 lb. per inch of diameter. The racer illustrated in Fig. 2, Plate 61, weighs from 18 lbs. to 25 lbs. according to the size of the driving wheel. The weight of a 54-inch bicycle is divided amongst its several parts in the following approximate proportions:—

Driving wheel with cranks	40 per cent.
Steering wheel	7½ „
Front fork with head, handle-bar, and brake fittings .	25 „
Backbone with spring	17½ „
Saddle and pedals	10 „
	100

Vibration. — One of the chief improvements has been the introduction of rubber cushions in various parts of the machine, for absorbing and lessening the vibration which is the one great discomfort of cycle riding. Figs. 6 and 7, Plate 62, show the addition

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of rubber cushions round the bearings of the front wheel, and Fig. 5 round those of the back wheel. Fig. 3 shows the suspension of the spring on rubber buffers RR. Fig. 4 shows the method of severing the metallic contact between the handle-bar and the head which carries it, by interposing between them a set of rubber rings secured and tightened by a gland. By these means Mr. Salamon, the inventor of this plan, has brought his "Matchless" bicycle to a high state of perfection; and the tricycle has also been similarly improved, with the same beneficial results. As a large proportion of the vibration in travelling over a rough road arises from the small trailing or steering wheel, various arrangements have from time to time been devised for absorbing it. One which acts most beneficially in practice is illustrated in Fig. 8, Plate 63, and consists of a spring fork applied to the steering wheel of a front-steering tricycle. It will be seen that the wheel is carried in an auxiliary fork which is pivoted to the ends of the prongs of the ordinary fork, so that the wheel is free to rise and fall within certain limits, which are defined by the elasticity of helical springs controlling the horizontal play of the top of the auxiliary fork.

Dwarf Bicycles with geared rotary action.—Machines of the second class, as illustrated in Fig. 9, Plate 63, are constructed with a smaller driving wheel; and the power, instead of being applied direct to the driving wheel, is transmitted to it through a pair of chains and chain-wheels from a divided pedal-axle placed below and slightly in the rear of the driving-wheel axle, so that the rider's feet are much nearer the ground. The use of chains and chain-wheels to connect the pedal-axle with the driving wheel permits the latter to be geared up, so as to be equal in speed to any desired size of driving wheel; and also permits the use of long cranks, independent of the length of the rider's legs. To this is to be attributed in the author's opinion the efficiency of this type of machine; for as its weight is not less than that of an ordinary ungeared machine, while the internal friction is of necessity greater, some extraneous reason must be assigned to account for its ease of propulsion and consequent speed. One such reason may be

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the fact that the low speed of pedalling does not produce so much exhaustion as is experienced from a more rapid movement of the legs.

Within certain limits a machine of this class may be adjusted to suit riders of any height, by raising or lowering the pedal-axle brackets and shortening or lengthening the chains. A simple method of effecting this adjustment without altering the length of the chains is illustrated in Figs. 11 and 12, Plate 64. The lower ends of the fork F carrying the pedal-axle brackets B are hinged at the centre of the driving wheel, so that the brackets may be turned thereon for adjusting the height of the pedal-axle P from the ground.

The divided pedal-axles are each carried in a long bearing, with the chain-wheel mounted on one side of it and the crank on the other. Unless the bearing is made exceptionally long, which has the great disadvantage of increasing the width of the tread of the machine, it soon gets loose and shaky under the cross-winding strain put upon it. To obviate this defect, two special bearings have been introduced. In the one illustrated in Fig. 13, Plate 64, the bracket B carrying the axle P is forked, so as to carry two bearings, between which the chain-wheel W is mounted. In the other, illustrated in Fig. 14, the crank C is fixed on a prolongation of the boss of the chain-wheel W, which is itself mounted on a suitable ball-bearing upon a stud axle S fixed to a prolongation F of the fork. In this arrangement all cross-winding strain is avoided, while the tread of the machine is no wider than that of an ordinary direct-action bicycle.

Dwarf Bicycles with lever action.—Of dwarf bicycles propelled by a lever action the "Facile," illustrated in Fig. 10, Plate 63, is a prominent example. The fork of the front wheel is extended below the driving axle, and on the ends of the prongs are pivoted two pedal-levers, worked at their free ends by the feet. The levers work the cranks through connecting-rods so arranged as to increase the effective leverage. The action of the feet is simply reciprocating, the path of the pedals being only an arc of a circle of which the radius is equal to the length of the lever. There is here no multiplication of the speed by gearing, inasmuch as the pedal levers act direct on

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the driving wheel through the connecting-rods and cranks, and the reciprocations of the feet are accordingly equal in number to the revolutions of the driving wheel.

In another type of lever-action machine, the "'Xtraordinary," illustrated in Fig. 15, Plate 65, the pedal levers are suspended from short links pivoted on the prongs of the driving-wheel fork near their junction at the head; and the pedal levers are themselves connected direct to the cranks, being afterwards curved backwards to bring their free extremities well under the rider's feet. Here the path of the pedals is an ellipse, being a mean between the complete circle of the purely rotary machines, and the circular arc of the simply reciprocating. The front fork is here made to rake backwards, so as to keep the centre of gravity well behind the axle of the driving wheel; and owing to the consequent safe position of the rider a larger driving wheel can be used without seriously curtailing the safety of the machine.

Safety Bicycles with steering wheel in front. — Another safety bicycle, illustrated in Fig. 16, Plate 65, has the steering wheel placed in front of the driver. The rider sits as much over the driving wheel as possible, and drives a pedal crank-axle, which is mounted immediately in front of the driving wheel and is geared to it by a chain and pair of chain-wheels. A through pedal-axle can here be used, and consequently only a single driving-chain is necessary. But by using a divided pedal-axle and two chains, as shown in Fig. 17, Plate 66, the rider can sit more directly over the driving wheel, and can thus take a great deal of the weight off the steering wheel, which enables the machine to run easier and to be more easily steered. The saddle and the pedal-axle are mounted on an independent frame, pivoted on the axle of the driving wheel and free to swing either backwards or forwards; and a locking detent attached to the main frame engages with a notched sector fixed to the top of the swing frame, and locks the swing frame to the main frame. By this arrangement the rider is enabled to shift his position so as to keep his weight directly over the driving wheel on any gradient. As the swing frame is pivoted at the centre of the driving wheel, the length

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of the chains is constant in every position. A similar arrangement is also fitted to tricycles, as will hereafter be described. As the rider on this type of machine is seated upon the frame on which the pedal crank-axle is mounted, the power exerted on the pedals has no effect on the steering; and therefore this bicycle cannot be steered by the feet, as the ordinary bicycle can. The steering wheel is controlled by a transverse handle-bar, connected to the steering-wheel fork either directly, as illustrated in Fig. 16, Plate 65, or indirectly by means of levers and connecting-rods, as illustrated in Fig. 18, Plate 66. A modified form of this bicycle is illustrated in Fig. 19, Plate 67, in which the steering wheel is made larger than the driving wheel; this renders the steering less sensitive, though it adds materially to the weight of the machine and certainly does not improve its appearance.

Owing to the position of the steering wheel in front of the driving wheel, the steering is rather sensitive and consequently erratic, and various means have been contrived to keep the front wheel running in a straight line; but as any such devices tend to destroy the sensitiveness necessary for maintaining a balance, they have not always had the desired effect. When this difficulty is overcome, this type of bicycle will excel its competitors, as it is almost absolutely safe, and moreover is almost entirely free from vibration, owing to the position of the rider being nearly midway in the length of the wheel-base, which causes the machine to have a gentle rocking action over rough roads. By the arrangement illustrated in Figs. 24 and 25, Plate 69, the difficulty of controlling the steering has been overcome by the author with a certain measure of success, by connecting the pedal crank-axle with the transverse handle-bar, so that the feet turn with the handles, thus permitting of the steering being controlled by the feet, as in an ordinary bicycle. The rider is thereby enabled both to steady the machine and to balance himself with his feet as well as with his hands, and also to steer by means of his feet alone when desired. The pedal crank-axle A is mounted in a bracket B fixed to the vertical rod V, which carries the transverse steering handle-bar, and which is mounted in a suitable bearing F fixed to the frame of the machine. On the

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centre of the axle is formed a ball or sphere, on which is mounted a duplex chain-wheel C; a pin P passes through the wheel and the axle, and forms the driving connection between them. In order that the axle may swivel in a horizontal plane during any position of the chain-wheel, a slot is cut through the sphere to allow of the free swivelling of the driving pin. Instead of using a duplex chain-wheel, a single one overhung may be used, with an internal bearing to take the pull of the driving chain; but the duplex method illustrated is preferable on account of its simplicity. The two chains then divide the work between them, and balance each other in the direction of their pull. Two small rollers R R mounted on the bearing F bear against the rim of the chain-wheel, and take the upward component of the pull. This steering arrangement is also applicable to central-driving tricycles steered with a transverse handle-bar, in which case the chain-wheel is mounted directly central with the sphere on the pedal-axle, and therefore requires only a bearing on each side to steady it.

Tandem Bicycles.—Of these there are as yet but two makes, both of which have been originated by Mr. Rucker. The earlier one, illustrated in Fig. 21, Plate 68, is constructed of two ordinary bicycle driving-wheels complete in their forks; and the forks are then connected by a backbone, which contains in its length a swivel or axial joint. Each rider drives his own wheel, sitting just behind its centre; and each steers independently of the other for balancing himself. The axial joint in the backbone, and the joints formed by the heads of the forks and the bearings of the wheels, together make a perfect universal joint between the two wheels. Within certain limits the rear rider has of course to follow in the track of the front wheel; otherwise the heads of the two forks become locked and a dismount is rendered necessary. Although this machine is very fast, lighter than two ordinary bicycles, and almost entirely free from vibration, there is an element of danger about it that militates against its general use, inasmuch as it demands to a certain extent a unity of thought and action on the part of the two riders.

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From a tricycle designed as a modified form of this bicycle, and illustrated in Fig. 22, Plate 68, very satisfactory results have been obtained by the author. Instead of having two bicycle driving-wheels, it is constructed with one bicycle driving-wheel in front and a pair of driving wheels behind belonging to a Humber tricycle, which are connected with the front wheel by a similar backbone. As the rear rider does not require to balance himself, he has nothing else to attend to than to follow the front rider; consequently the greatest element of danger is removed. This machine would probably give better results if the direct-action bicycle wheel were replaced by a small wheel with a geared rotary action. Its efficiency is doubtless due to the equal distribution of the wheel load, and to the fact that all the wheels are drivers.

The later tandem bicycle, illustrated in Fig. 20, Plate 67, eclipses the earlier, and bids fair to prove the fastest cycle yet produced. It is constructed on the lines of a dwarf geared bicycle. The seat for the front rider is mounted immediately over the centre of the driving wheel; and that for the rear rider, who steers the machine, is nearly midway between the two wheels. Divided pedal-axles are mounted fore and aft of the driving-wheel axle, with which each is connected by a chain and chain-wheels. The front rider being seated on the fork carrying the driving wheel, which is also the steering wheel, has no control over the steering, which is therefore left entirely to the rear rider. The weight of this bicycle is only 55 lbs., and it is therefore the lightest machine yet made to carry two riders.

Otto Bicycle.—This peculiar machine, illustrated in Fig. 23, Plate 68, and due to the brother of the inventor of the gas engine known by the same name, is almost more nearly allied to a tricycle than to the bicycle proper; but as it has only two wheels, and consequently requires the balance to be still maintained by the rider, it is rightly called a bicycle. The wheels are of equal size, and are here mounted loose on the same axle, parallel to each other, and both of them are drivers. The rider sits between them, and works a continuous pedal crank-axle, the position of which, when he is seated, is below and slightly in front of the axle carrying the driving wheels.

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The crank-axle is connected with the driving wheels by endless steel bands, passing round plain pulleys on the ends of the crank-axle and on each wheel. The bands are kept taut by tightening springs, and the machine is steered by slacking one or other of them, which causes the corresponding driving wheel to lose motion, and therefore the other wheel over-runs it. If a very sharp turn has to be made suddenly, a brake is applied to one wheel at the same time that its driving band is slackened, which causes the machine to turn round in a circle upon that wheel as the centre. This machine having no small wheel fore or aft, the rider, while steady sideways, has to balance himself in the direction of his motion, which he is enabled to do through the medium of the pedal crank-axle; by pressing on the forward pedal, if he is falling forwards, he throws his weight backwards; and by pressing on the rear pedal, if he is falling backwards, he throws his weight forwards. To preserve him from actually capsizing backwards, a safety tail projects behind the seat, carrying a small roller at its extremity, which will bear upon the ground whenever the seat is tipped too far back. Among the many beautiful features presented by this machine the best seem to be:—firstly, its balance, whereby the rider is always in the best position to utilise his strength and weight, notwithstanding the varying gradients; secondly, the nicety with which it can be steered; thirdly, its tendency to run in a straight line without any effort on the part of the rider; fourthly, its freedom from vibration; fifthly, the circumstance that it makes only two tracks; and sixthly, the perfect distribution of the wheel load.

Power.—On the power expended in the propulsion of cycles some experiments have already been made. In a paper read before the Royal Dublin Society, Messrs. G. J. and G. G. Stoney gave the results of a series of experiments carried out by them, which showed that the power required to propel a bicycle on an average road was between one-seventh and one-third of a horse-power, according as the speed varied between six and fourteen miles per hour. These figures must be taken only as approximate, because the experiments were made on a lever-action machine, Fig. 15, Plate 65, which adapts

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itself more readily for attaching and working a diagram indicator than machines with a rotary action; and the author believes that a rotary-action machine would give better results.

Tricycles.

The tricycle presents far greater difficulties than the bicycle. It is necessary that any one of its three wheels shall be free to move in its own direction, independent of the united action of the other two. For running in a straight line, all three wheels must be parallel; whilst for running round a curve, one or more of the wheels must be turned until the centre lines of the axles intersect in plan, their point of intersection being the centre of the curve round which the machine will then run; therefore the more acute the angle of intersection, the greater will be the radius of the curve; and inversely, the more obtuse the angle, the sharper will be the curve. Besides being independent in direction of running, each wheel must also be capable of revolving at a greater or less speed than the others. It is also essential that the greater part of the rider's weight shall be on the driving wheel or wheels, and that only enough shall be on the steering wheels or wheel for ensuring their proper action. Owing to the variety of ways in which these principles can be carried out practically, it is easy to account for the variety of tricycles constructed.

Single-driving Tricycle.—The simplest form of tricycle is obviously that with only one driving wheel, either or both of the others being used for steering. An early type of single-driver, now practically obsolete, had two large wheels mounted opposite and parallel to each other, one of which was driven, and the other was allowed to run free; the third or steering wheel was placed centrally in the rear.

Coventry Rotary Tricycle.—Another single-driver, illustrated in Fig. 26, Plate 70, and known as the "Coventry Rotary," has the large driving-wheel on one side, and two small steering wheels on the opposite side, placed respectively fore and aft of the driver, and arranged to turn together but in contrary directions. The double steering, fore and aft of the driving wheel, overcomes the tendency of the machine to run in a curve in consequence of the single driving-

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wheel on one side. This was one of the first tricycles introduced, and has stood the test of competition, being at the present time one of the most popular. Its chief features are that it is simple in construction, makes only two tracks when running, and is narrow in width. Its narrowness, although rendering it somewhat unstable in running round a curve at a high speed, allows of its passing through a doorway of ordinary width. This machine was the invention of the late Mr. James Starley, who has justly been styled "the father of the cycle industry," and to whose memory a monument has recently been erected on a public site in Coventry.

Front-steering Tricycle.—The third and last kind of single-driver, as illustrated in Fig. 27, Plate 70, has the driving wheel placed centrally in the rear of two steering wheels, which are mounted parallel and opposite to each other. The defect of this arrangement is that the weight of the rider is too equally distributed over the three wheels, instead of coming more upon the driver than upon the other two.

Double-driving Tricycles.—In these the two driving wheels are always placed parallel and opposite to each other, with the steering wheel in front or behind and generally central; though in some cases it is placed in line with one of the driving wheels, so that the machine then makes only two tracks, as illustrated in Fig. 32, Plate 72. There are two methods of double driving:—firstly by clutch action, and secondly by differential or balance gear.

Double driving by clutch action.—In this plan the two driving wheels, or the chain-wheels driving them, are locked to their axle while the tricycle is being driven forwards in a straight line; but in running round a curve the outer wheel over-runs the clutch, and the inner wheel alone drives. As only one wheel drives when the machine deviates from its straight path, the clutches in order to drive satisfactorily must be instantaneous in their action, in order that both driving wheels may be locked to their respective chain-wheels or axle immediately on the machine again running in a straight line. Of the many various clutches that have as yet been devised, none have produced better results than that known as the Bourdon

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clutch, which is illustrated in Fig. 28, Plate 71, as applied to the pedal crank-axle. It consists of a disc D, fixed on the crank-axle A, and having its circumference cut away so as to form three or more inclined planes. A cylindrical box B, forming the boss of the chain-wheel C, encircles the driving disc D; and in the recesses of the inclined planes are placed small rollers R R, which jam between the disc D and the box B, and so lock the two together as long as the axle is driving the wheel. Whenever the wheel has freed itself by over-running the axle, it will be seen that in every position there will always be at least one of the rollers ready to lock the wheel to the axle again instantaneously as soon as ever its speed falls back to that of the axle.

A clutch-driven machine of course cannot be driven backwards without some extra gearing; nor can it be stopped by back pedalling, and in consequence the burden of checking the speed is thrown entirely on the brake. As a set-off against this disadvantage, the pedals are free to remain stationary while the machine is continuing to run forwards: an advantage which certainly economises the expenditure of power, inasmuch as the feet can rest motionless on the pedals whenever the gradient of the road will allow the machine to run of itself. Various attempts have been made to construct a clutch that will drive automatically in both directions, but all have proved unsuccessful in consequence of not being instantaneous in action; and it appears impracticable to make a clutch which shall drive in both directions without allowing a small amount of back-lash between the forward and the backward grip. If a clutch could be made to act instantaneously in both directions, it would form a better double-driving gear than the differential or balance gear, which at the present time is the best plan of double driving for general application. Having been asked some time ago to devise a means of making a clutch drive in both directions, the author has taken the Bourdon as a perfect clutch for driving in one direction; and from the experiments he has thus far made he hopes to succeed in the object aimed at.

Double driving by differential or balance gear.—This other mode of double driving, so called because the power is divided or "balanced"

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between the two driving wheels, consists of an epicyclic train in which the two primary wheels are each connected directly or indirectly with one of the driving wheels of the tricycle, while they are also connected with each other through an intermediate loose train of mechanism carried by an arm. The simplest form of differential gear is that shown in Figs. 29 and 30, Plate 71, and invented by the late Mr. James Starley, who first applied it to tricycles. It somewhat resembles an ordinary reversing train, being constructed of three bevel wheels: one of the two facing wheels A is fixed to the hub of one of the driving wheels, which runs loose on the axle; and the other is fixed on the driving axle, on the end of which the other driving wheel is fixed. Between the two facing wheels is mounted the chain-wheel C, which runs loose on the axle, and carries loose on a radial axis the small bevel pinion P gearing permanently with the two facing wheels. So long as the tricycle is running in a straight line, both of the driving wheels are driven equally by the chain-wheel C, the two facing wheels being simply dragged round by the intermediate pinion P, which at that time is not rotating round its own axis. But when the tricycle is steered in a curve, the inner driving wheel revolves at a slower rate than the chain-wheel; and consequently the outer driving wheel is driven through the bevel gear at a correspondingly higher speed, in whichever direction the machine is running, whether forwards or backwards.

There are many various forms of differential gear, some of which are exhibited; as the result produced by each is identical, it is not necessary to describe all of them in detail. But there is one which from its construction is specially suitable for central-geared machines, and is illustrated in Fig. 31, Plate 71. The driving axle A A, on the ends of which are fixed the driving wheels, is divided in the middle of its length; and the two half lengths are united by a coupling box B, which has a long tubular neck N at each end, running loose upon the axle, and carried in the bearings of the machine. On one neck is fixed the chain-wheel C, by which the coupling box B is driven. Inside the coupling box are two short parallel shafts S, inclined at 30° to the driving axle, and geared together by equal pinions P; one end of each shaft is carried in a socket in the coupling box, and

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the other end is connected by a universal joint to the opposite half of the driving axle. Another form of differential gear has been constructed to work through the crank-axle, for use on open-fronted rear-steering machines; but it is not a practical success, owing to the intricacy and extra weight entailed.

In a clutch-driving machine it will be seen that the same amount of power is always applied to each of the driving wheels, so long as the machine is running in a straight line, and that no extraneous resistance to either wheel will deprive it of its half share of the total power. In a machine driven by differential gear each wheel receives its due proportion of power: thus, in running in a straight line, each wheel receives half the total power, and in running round a curve each receives the proportion due to its relative speed. This so far is as it should be; but if, while the machine is running in a straight line, one wheel encounters greater resistance from the ground than the other, this wheel ought in a perfect double-driving machine to receive a larger share of the power. With none of the existing forms of differential gear however is this result attained. The action of the two kinds of gear can be practically tested by taking two machines, one driven by clutch action and the other by differential gear, and disconnecting the steering wheel so that it may trail and run free. If while these machines are driven straight forwards an obstruction be placed in the path of one of the driving wheels of each, the clutch-driven machine, if its impetus be sufficient, will pass over it without deviating from the straight line; but the differential-geared machine will swerve round to the side on which the obstacle occurs, and will probably fail to pass over it. In differential-geared machines therefore it is important to have sufficient weight on the steering wheel for ensuring its controlling the action of the differential gear. Fig. 33, Plate 72, illustrates a rear-steering tricycle driven by differential gear; Fig. 34, Plate 73, a rear steerer driven by clutch action; Fig. 35, Plate 73, a front steerer driven by differential gear.

Humber Tricycle.—Among the tricycles driven by differential gear, the one known by this name after its inventor is widely

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different from all others, as illustrated in Fig. 36, Plate 74. The rider sits astride a backbone carrying a trailing wheel, and steers by turning the two driving wheels by means of a transverse handle-bar, as is done in a bicycle. To the dwarf bicycle its appearance bears a considerable resemblance, except that on a bicycle the rider sits over the single driving-wheel, whereas on the Humber tricycle he sits between the two driving wheels. The efficiency of the differential gear as a means of double driving is specially prominent in this machine, because it allows the driving wheels to be used as steering wheels without in any way affecting its double-driving properties.

In Fig. 37, Plate 74, is illustrated a modification of the Humber tricycle, which is steered by a pair of upright spade-handles, instead of by a transverse handle-bar. The backbone is connected with the frame carrying the driving wheels by an arrangement of friction discs, instead of by the usual head, so that the sensitiveness of the steering may be varied to suit individual likings. This machine is further designed so as to be easily taken to pieces for convenience of transport.

In the latest development of this type of tricycle, illustrated in Fig. 38, Plate 75, the usual backbone is dispensed with, and the frame consists of but one central tube, which is curved upwards and backwards to carry the seat, and downwards and backwards to carry a vertical swivel-joint or head; to this is attached a horizontal fork carrying the rear wheel, which is connected by suitable rods and levers to a transverse handle-bar whereby the machine is steered. Although the steering mechanism is connected directly with the rear wheel, the machine is not an actual rear-steerer, because, owing to the intermediate position of the steering head, all three wheels turn in unison, the driving wheels turning in the opposite direction to the rear wheel. The advantages of this tricycle over the ordinary Humber type seem to be:—first, that the pressure on the pedals has no effect on the steering of the machine; secondly, that the steering is less sensitive; thirdly, that the rear wheel always runs in a track central with the driving wheels, whether running on a curve or in a straight line; and fourthly, that the tricycle can be driven and steered with equal facility either forwards or backwards.

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As already described in regard to bicycles, there are two methods of driving a tricycle: firstly, by rotary action, in which case the power is applied either directly to a cranked axle carrying the driving wheels, or to a cranked pedal-axle connected with the driving-wheel axle through an endless chain or other means; and secondly, by lever action, where the power is applied by reciprocating pedal-levers, from which the motion is communicated to the driving-wheel axle through cranks and coupling-rods or otherwise. The lever action lends itself most aptly to obtain varying power; but in speed the rotary action is superior. The reason would seem to be that in the lever action the direction of force is changed so suddenly that in rapid pedalling a certain amount of back pressure is unavoidable.

Omnicycle.—One of the most successful lever machines is the Omnicycle, illustrated in Fig. 39, Plate 75. Its success is due to the variable-power gear with which it is fitted. The pedal levers are connected by bands to two expanding segments, which are each connected to the driving axle by clutches, and to each other by a reversing apparatus, so that the forward movement of the one produces the backward movement of the other, and thus the descending pedal raises the other ready for the next stroke. The segments are constructed so that they can be expanded or contracted, so as to give greater or less leverage, as shown in Figs. 40, 41, and 42, Plate 76, in which the segments are represented at their extreme and mean radii from the driving axle A.

Direct-action Tricycle.—Of rotary tricycles the simplest form is that illustrated in Fig. 46, Plate 77, with the two driving wheels mounted on the ends of a cranked axle and connected to it by clutches, the rider driving the axle direct. This arrangement simplifies the construction, and reduces the working parts; but it has the one insuperable objection of instability, owing to the high position of the centre of gravity. In another tricycle, Fig. 47, Plate 77, swinging pedals are hung from the cranked axle, whereby the centre of gravity is slightly lowered and the machine rendered somewhat more stable.

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Transmission of Driving Power.—Reverting to the ordinary type of tricycle, in which the power is applied to a cranked pedal-axle and thence transmitted to the driving axle, there are three principal methods at present in use for its transmission:—firstly, by chains or bands; secondly, by gear wheels; thirdly, by cranks and coupling-rods. Many other plans have also been tried at various times.

Driving Chains.—These are the most popular means of transmitting the driving power, as they offer the greatest facilities for gearing the driving wheels up or down. Samples of the various chains in use are exhibited; but the only two calling for any special notice are the Morgan and the Abingdon. The Morgan chain, shown in Fig. 43, Plate 76, is composed of rectangular links made of round steel wire, which alternate with hollow steel rollers. The chief feature of the Abingdon chain, shown in Fig. 53, Plate 80, is that, with the exception of the pins which rivet the links together, all the parts are of one uniform pattern; and the side plates of the links being so constructed that the ends break joint with one another, the chain can be shortened or lengthened by only one link at a time, whereas all other chains require two links for alteration in length.

Driving Bands.—Steel bands, either plain or perforated, have been used with some success. The Otto bicycle is the only machine on which plain bands are used for driving, a tension being exerted between the bearings of the two axles so as to keep the bands taut. Perforated bands have also been used, with toothed pulleys. But the power expended in the continuous flexure of bands in passing over their pulleys outweighs any other advantages they may have.

Gear Wheels.—In this mode of driving, an intermediate wheel gears with those on each axle; but as the wear cannot be taken up without destroying the pitch-line of the teeth, the plan does not prove satisfactory in practice. The teeth of the intermediate wheel are sometimes fitted with rollers to lessen the friction, as shown in Fig. 50, Plate 79. The two axles have also been connected by a vertical shaft, carrying at each end a bevel wheel, which gears with other bevel wheels on the respective axles, as shown in Fig. 49,

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Plate 78. This arrangement is open to the same objection as the preceding one.

Coupling-Rods.—Cranks and coupling-rods are used on some tricycles, as illustrated in Fig. 48, Plate 78. With the exception that they will not permit of the driving wheels being geared up or down, and that they cannot be used with a differential gear, they give very good results.

The latest method of communicating motion is a combination of eccentrics and steel bands, invented by Mr. C. Vernon Boys. Eccentrics being equivalent to cranks, two equal eccentrics are fixed on each axle with their throws opposite; and an endless steel band embracing each pair acts as a coupling-rod between them.

Variable-Speed Gear.—Various arrangements have been introduced for varying the speed of the driving wheels in relation to that of the pedal crank-axle, whilst the tricycle is in motion, so as to obtain varying degrees of power for suiting the exigencies of the road. There are the five following methods of doing this.

1st. A set of change-wheels may be thrown in and out of action as desired.

2nd. An epicyclic train may be used, which for one speed is locked together and moves as a single piece, and is set in motion for the other speed. These gears are constructed so as to be quiescent at either the higher speed or the lower. In Figs. 51 and 52, Plate 79, is illustrated a two-speed gear in which the epicyclic train is quiescent at the lower speed and in motion at the higher. On the end of the crank-axle A is mounted a loose chain-wheel C, having a ring of internal teeth. Fixed on the axle is a boss B with four arms, on each of which is centered a small live pinion P. The four pinions gear with the internal teeth in the chain-wheel C, and also with a central pinion E mounted loose on the outside of the four-armed boss B. Pivoted to the boss of the central pinion E is a fork F, of which the spring handle engages in any one of a ring of notches cut in the edge of the chain-wheel, and thereby locks the pinion to the chain-wheel C: so that, when power is transmitted from the axle through the four arms,

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the whole train moves together as if it were a single piece, and the tricycle is driven at the normal speed to which it is geared by the chain-wheels. When it is desired to increase the speed, a wedge-faced arm conveniently pivoted on the frame of the tricycle is dropped, so as to throw the spring handle of the fork F out of its notch and hold it stationary; the central pinion E being thereby prevented from revolving, the chain-wheel C will be driven at a higher speed than the crank-axle, owing to the revolution of the four live pinions P round the stationary central pinion E.

In Figs. 54 to 57, Plate 80, is illustrated a converse arrangement of two-speed gear, known as the crypto-dynamic or "crypto" gear, which is quiescent at the higher speed and in motion at the lower. In Fig. 54 is shown an outside view of the gear as closed up complete. In Fig. 55 is seen the interior of the gear, when the internally toothed driving wheel is removed, which is shown separately in Fig. 56. In Fig. 57 is shown a longitudinal section of the gear to a larger scale. The internally toothed wheel D is keyed on the axle A, and is therefore the driver. The four intermediate live pinions P are mounted on the chain-wheel W, and the central loose pinion L is fitted with a clutch C, so that it may either be locked to the chain-wheel, or be held stationary by the back B of the casing. In the former case, the whole train revolves as one piece, and the tricycle is driven at its normal speed; but when the central pinion is held stationary, the chain-wheel runs slower than the axle, owing to the speed lost through the live pinions P revolving round the stationary central pinion L.

3rd. A third plan is to use two sets of chain-wheels and chains, one gearing for power and the other for speed, either of which can be connected or disconnected at pleasure.

4th. Expanding chain-wheels can be used. Generally one only is employed, and an idle pulley is provided for taking up the slack of the chain when the wheel is at its smallest diameter. A specimen of an expanding chain-wheel is exhibited, in which the pitch of the teeth is never altered.

5th. Another method of obtaining increased power is to use cranks with a variable throw. The simplest form is illustrated in

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Figs. 58 to 66, Plate 81, which show a left-hand crank, the right-hand one being of a similar construction with the locking parts reversed. Each crank is quite independent of the other. On each end of the axle A is fixed an eccentric E, their throws being opposite to each other. The crank C is formed with a strap S passing round the eccentric, and is provided with a pawl D, which engages with either one of two ratchet-teeth R cut in the circumference of the eccentric, and locks the crank to the eccentric at one or other of the two throws, so that motion may be communicated to the axle when the crank is moved forwards. A flat spring F produces frictional resistance between the eccentric and the strap, sufficient for lifting the rising pedal. In order that the rider may be enabled to exert a retarding force through the crank while it is rising, for the purpose of checking the speed of the machine or of driving it backwards, a gravitating bolt B, sliding loose in a diametrical direction across the eccentric, engages with a tooth J cut on the inner edge of the crank strap S, thus locking the eccentric to the strap against any backward pressure. The action of this gravitating bolt is such that it locks the crank to the eccentric when the pedal is rising, Figs. 61 and 62, so that back pressure may then be exerted; and unlocks it when the pedal is falling, Figs. 59, 60, and 63. Consequently if the crank be prevented from rising when it reaches the bottom, in which position the gravitating bolt is just on the point of reversing itself, Fig. 60, the throw of the crank will automatically alter itself, Figs. 64 and 65, and will lock itself in the other position, Fig. 66, providing there is sufficient momentum in the machine to carry it forwards through half a revolution. For inasmuch as each crank is quite independent of the other, and can be altered only when in one position—namely when it reaches the bottom of its stroke—each crank requires half a revolution of the axle for effecting its alteration. Thus if the right-hand crank be held stationary at the bottom of its stroke, its throw will be altered during the next half-revolution of the axle, during which the left-hand crank will also have come down to the bottom of its stroke, where it will then be held stationary during the following half-revolution for altering its throw, while the right-hand crank will be rising to the top of its stroke; and during this

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latter half-revolution neither crank will be exerting any forward driving power. On its completion the two cranks will then be on opposite centres again, each with its altered throw.

Position of Rider.—In each different make of tricycle there is a certain position for the rider's seat, in respect both to the axle of the driving wheel and also to the pedal crank-axle, which when the machine is travelling along a level road will permit of the rider exerting his power to the best advantage. But on a gradient this position changes, and consequently the rider's position should also be altered. In ascending a hill, the position of the rider requires to be moved forward; which accounts for the strained attitude that some riders are obliged then to assume. The best position for the seat on a front-steering tricycle is generally 1½ inches in front of the driving axle and 7 inches behind the pedal-axle, this axle being therefore 8½ inches in front of the driving axle.

Various arrangements have been devised for enabling the rider to alter his position according to the gradient. The most perfect is the swing frame, as applied to the Devon tricycle by Mr. F. Warner Jones, which is similar to that applied to the dwarf bicycle illustrated in Fig. 17, Plate 66. It consists in mounting the saddle and the pedal crank-axle on a swinging frame, pivoted inside the main frame, so that it may swing backwards and forwards, and thereby place the rider in the best position for exerting his power. The swinging frame is provided with a locking apparatus for fixing it in any desired position relative to the main frame. Fig. 67, Plate 82, illustrates a tricycle fitted with a swing frame. Fig. 68 shows the position of a rider in ascending a hill on a machine without a swing frame; and Fig. 69 shows his position on one with a swing frame.

A modification of this arrangement has been introduced by Mr. J. Alfred Griffiths, as illustrated in Fig. 70, Plate 83, in which the swing frame is always on the balance, so that the rider's position corrects itself automatically within certain limits determined by a spring. As this subject will be dealt with by Mr. Griffiths in a paper of his own, it need not be anticipated here by further description.

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Another method of correcting the position for varying gradients is to mount the seat or saddle in such a manner that it may be moved backwards or forwards within certain limits without the rider having to dismount. In Fig. 71, Plate 83, is illustrated such an arrangement, in which the saddle is mounted on a sliding frame, so that it can be shifted forwards or backwards by a hand-lever acting through an arm and link.

Hand-Power Tricycles.—Various machines have from time to time been introduced in which the driving power is exerted by the arms, instead of by the legs; but as the power of the legs is normally greater than that of the arms, these machines cannot compete with the usual cycles, and are intended only to meet certain special requirements. Only two machines call for particular notice: the Velociman and the Oarsman.

The Velociman, illustrated in Fig. 72, Plate 84, is specially designed for those who have to depend either partially or entirely upon their arms for propelling power. It is constructed with a pair of driving wheels on a differential-geared axle, which is connected by an endless chain and pair of chain-wheels with a cranked counter-shaft; the latter is driven by a pair of hand-levers connected to a light rocking frame, which is pivoted on the front part of the main frame of the machine. The rocking frame also carries a footboard, by which the power of the legs may be exerted whenever practicable. A rear steering wheel is controlled by a pad behind the seat, against which the rider leans back.

The Oarsman, illustrated in Fig. 73, Plate 84, is driven by an action similar to rowing. It has two driving wheels, loose on their axle, and a rear steering wheel. It is driven by cords which actuate clutches attached to the driving wheels; after passing round the clutch-drums the cords are carried round small pulleys mounted on the front part of the frame of the machine, and turning upwards are then attached to a sliding or rocking frame which carries the seat. A cross-bar connects the two cords, and the machine is propelled by pulling the bar backwards, and at the same time sliding the seat also backwards by the action of the legs, similarly to rowing. When

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the seat is slid forwards again after each stroke, coiled springs in the clutch-boxes rotate them back into their normal position, ready for the next stroke. Although this machine is classified under hand-power tricycles, almost all the muscular power of the body can be utilised in its propulsion.

Sociable Tricycles.—Of tricycles to carry two riders there are two kinds, the "Sociable" and the "Tandem." In the former, the riders sit side by side; in the latter, one behind the other. The Sociable is merely an enlargement of the single form of tricycle, with some parts in duplicate. Some Sociables are capable of being converted into single machines, that illustrated in Fig. 76, Plate 86, being the simplest. In its single form this is a "Coventry Rotary," illustrated in Fig. 26, Plate 70, the part that is attached to make the double machine being simply a duplicate of the single half, without the two steering wheels and steering gear and the tube that carries them, as illustrated in Fig. 77, Plate 86, which shows the single machine and the detached half. As the machine in its double form has four wheels on the ground, the added half is connected to the single machine by a hinge joint, as illustrated in Fig. 79, Plate 87, so that it may accommodate itself to the inequalities of the road; P is the coupling pin connecting the added part A, which contains a hinge joint H having a slight clearance at C for vertical play. Figs. 74 and 75, Plate 85, illustrate a convertible Sociable of the ordinary front-steering type, the former showing it in its double form, and the latter in its single form, with the detached part by the side of it.

Tandem Tricycles.—In these there is more scope for variety, and the different machines may be classed as follows:—

1st. The ordinary front or rear-steering tricycle, illustrated in Fig. 80, Plate 87, in which the wheel base is extended, so that the riders may be seated fore and aft of the differential-geared driving-axle without destroying the balance of the machine.

2nd. The Humber tandem, Fig. 81, Plate 88, in which the extra rider is seated in front of the driving axle, but as nearly over it as

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possible, and communicates motion to it from a pedal crank-axle in a similar manner to the rear rider, who is seated further back than in the single machine, so as to counterbalance the extra weight in front.

3rd. The tandem tricycle in which an auxiliary trailing frame is fixed in the rear of an ordinary front-steering tricycle, as illustrated in Fig. 82, Plate 88, so that there may be plenty of room between the two riders. In order that the trailing frame may rise and fall with the inequalities of the road, and may follow properly when the machine is running round a curve, it is necessary to have both a transverse and a vertical joint between the two frames.

4th. The Coventry Rotary tandem, Fig. 78, Plate 86, which is similar to the single machine with the addition of a light frame, fixed in the rear of the front seat, to carry the hind seat and pedal crank-axle for the rear rider. This makes a very simple and efficient machine, except that it intensifies the weight to be carried by the single driving wheel. It is also easily converted into a single machine by removing the parts required for the second rider.

Tandems of the other classes are also made convertible into single machines; but those of the third class lend themselves most aptly to conversion, because the transverse joint or hinge forms a ready means for detaching the auxiliary trailing frame. Some of the machines of the third class, as illustrated by Fig. 82, Plate 88, are constructed so that they may be converted either into a single machine of the front-steering type, as illustrated by Fig. 92, Plate 93, or into the Humber type, as illustrated by Fig. 36, Plate 74. To a combination of these two machines, with an axle and pair of driving wheels common to both, the tandem shown in Fig. 82, Plate 88, bears a strong resemblance. This is effected by coupling both the front and the rear frame to the bearing cases on the driving axle by hinged couplings, either of which is capable of being locked to the bearing cases when the other part of the frame is removed.

In nearly every convertible tandem it is necessary to disconnect one of the chains, in order to remove the auxiliary part of the frame. The usual method of effecting this is to connect two links of the chain by a small screw-pin and nut, which may be easily removed;

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but Messrs. Starley Brothers have recently perfected a disengaging link, which permits of the chain being easily connected and disconnected without having any loose pieces, as shown in Figs. 44 and 45, Plate 76. The link L at one end of the chain is made with a hollow rivet R, which carries the usual roller. The link at the other end of the chain is made with one of its side-plates H hooked so as to be capable of being opened or released from its rivet pin P; this allows of the pin being then inserted through the hollow rivet R of the link L, in which it is then locked by closing the hooked side-plate H. The hook itself is slightly bent out of the straight, and so requires a certain amount of side pressure to snap it over the head of the rivet pin P, which engages in a recess cut in the face of the hook H, and so locks it against possible accidental unshipment.

In Fig. 83, Plate 89, is illustrated an auxiliary frame suitable for attaching to any front-steering tricycle so as to convert it into a tandem. It is provided with both vertical and transverse joint; and can be the more easily attached and detached because the power is transmitted to its own wheel, instead of to the driving axle of the tricycle to which it is attached.

Carrier Tricycles. — The last kind of tricycle, and the most useful of all, is that for carrying a burden. At the present time there is but one tricycle specially constructed for carrying a passenger, although there are several which are capable of being adapted for the purpose. This is illustrated in Fig. 86, Plate 90, and is known as the "Coventry Chair," being an ordinary Bath chair in which the pair of large wheels are replaced by part of a tricycle frame carrying a pair of driving wheels, with pedal crank-axle, and seat for the driver in the rear. As long ago as 1670 a Bath chair propelled by a rider was described by Jacques Ozanam in his French work, "Recreations in Mathematics and Natural Philosophy." Although the Coventry chair has been introduced only a short time, a large number are in use; and some are plying for hire, though the make seems to be too cumbersome for this purpose, for which it could hardly have been intended originally. As an instance of what can be done with these chairs, one was propelled

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from Coventry to London, a distance of 95 miles, in 22 hours, with a passenger and 50 lbs. of luggage. Another was propelled from Walsall to Rhyl, a distance of 110 miles, in 24½ hours, with a passenger weighing 10 stone and 60 lbs. of luggage, the driver weighing 14½ stone.

Of goods carriers there are a large number of makes, but there is nothing in their construction to call for special comment; their success depends chiefly on the load being balanced as much as possible on the driving wheels. In Figs. 84 to 89, Plates 89 to 92, are illustrated carriers adapted for various purposes. They are largely used by the post office: both for the delivery of letters in rural districts, Fig. 84; and for the parcel post, Fig. 85. They are also largely used by newspaper offices for the distribution of papers, Fig. 87; besides being used in almost every trade for the distribution of goods, Figs. 88 and 89.

Arrangement of Driving Gear.—All tricycles driven by a rotary action from a pedal crank-axle may be again subdivided into four classes:—1st, side driving and side geared; 2nd, side driving and central geared; 3rd, central driving and central geared; 4th, central driving and side geared.

In side-driving tricycles, whether side geared or central geared, the frame is generally of the loop shape illustrated in Fig. 35, Plate 73, being constructed of tubing in the form of a loop, which runs down from the bearing on each end of the driving axle in close proximity to the driving wheels, and carries the ends of the cranked pedal-axle, and then curving across carries the short backbone which projects forwards to carry the front steering wheel. The differential gear in the side-geared tricycles is fitted on one end of the driving axle, close up to one of the wheels, as shown in Fig. 30, Plate 71, &c.; and the gear transmitting motion to it from the pedal crank-axle is mounted outside the loop frame. In the central-geared tricycles the differential gear is constructed in the centre of the driving axle, while the driving gear is still kept at the side of the machine.

In central-driving tricycles, whether central geared or side geared, the frame is usually of a T shape, as illustrated in Fig. 91,

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Plate 93. The horizontal part, or top of the T, carries the bearings for the driving axle; and the vertical part or stalk, after running down to carry the bracket in which is mounted the short pedal-axle fitted with bicycle-cranks and pedals, is curved up again to carry the steering wheel. The differential gear in the central-geared tricycles is constructed in the centre of the axle, and is therefore in line with the driving gear. In the side-geared tricycles the differential gear is placed close up to one of the driving wheels, whilst the driving gear is kept in the centre. The central-driving and central-geared machine is obviously the most perfect, as equal power can thereby be distributed to both driving wheels. Although in practice no appreciable advantage is gained by central-geared machines over side-geared, yet theoretically the advantage lies with the central-geared, because the internal friction of each half of the gear and its attendant parts is the same; whereas in a side-geared machine the one half of the differential gear which is fixed to the driving axle has the friction of the bearings, while the other half which is fixed to one of the driving wheels has not. In central-driving tricycles it is most essential for the bearings carrying the driving axle to be so distributed that the bending strain caused by the pull of the driving chain shall not cause the axle to sag. In some central-driving machines the bow-sprit tube that carries the steering wheel is run out level from the horizontal part of the frame; and another tube slopes downwards for carrying the pedal crank-shaft bracket, as illustrated in Fig. 92, Plate 93; this makes a stiffer frame, though it limits the use of the machine to men only. The advantages of the T frame are its simplicity and lightness, and also that it permits the use of adjustable cranks.

Width.—As the width of a tricycle varies between 36 and 39 inches—excepting the Coventry Rotary, which from its special design can be made as narrow as 27 inches—many arrangements have been devised for temporarily reducing the width, so as to enable a machine to pass through an ordinary doorway. Two plans only call for special notice, namely folding frames and telescopic frames; all other devices consist in removing one or both of the

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driving wheels, or detaching some part of the frame. Folding frames are so constructed and hinged together that by removing one or more pins they may be folded up. Figs. 93 and 94, Plate 94, illustrate a tricycle with a folding frame, Fig. 93 showing it ready for riding, and Fig. 94 folded up. In telescopic frames, which are always used with central gearing, the frame and the axle on one side of the machine are made telescopic, so that by slackening one or two nuts the parts will slide one within the other. Figs. 95 and 96, Plate 95, illustrate a telescopic axle as applied to these machines, which is constructed as follows. A solid axle A carries upon one end the driving wheel which is in connection with the double-driving gear, the bearing of the end of the axle being in the cover of the gear box B; the other end of the axle terminates about 10 inches from the other side of the tricycle, instead of being continued right across the full width as in an ordinary machine. Upon it the outer tubular axle T slides with a key, and carries on its outer end the flanges F F of the hub of the other driving wheel. The tubular axle itself slides within the long tubular neck N of the gear box B, and revolves freely within it whenever the tricycle is running round a curve. A loose collar C, sliding outside the tubular axle T, is fixed to it by a set-screw S when drawn out to its full extent, so as to lock it in that position. A stop J is also fixed on the end of the solid axle A, against which the key of the tubular axle butts when drawn out fully; and by this means therefore the width of the machine is regulated.

Weight of Tricycle.—In a front-steering tricycle with a loop frame, having 50-inch driving wheels and weighing 80 lbs., the weight is divided amongst its several parts in the following approximate proportions:—

Driving wheels	31·2 per cent.
Steering wheel	5·0 „
Frame with steering and brake gear	27·5 „
Front fork	2·5 „
Pedal crank-axle with pedals and chain-wheel	13·8 „
Driving axle with differential gear	15·0 „
Seat-support with spring and saddle	5·0 „
	100·0

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Component Parts of Cycles.

Of the component parts of modern cycles the following alone call for special notice:—wheels, bearings, frame, steering gear, brake, and pedals.

Wheels.—It was through the introduction of "suspension" wheels that the first real advance was made in the improvement of cycles, as on that principle of construction the wheels can be made very light, rigid, and strong. They are constructed with either solid or hollow rims, the latter being the lightest and strongest. The ordinary make of wheel has a solid rim and direct radial spokes, which are threaded through holes in the rim and screwed direct into the flanges of the hub, being butt-ended or enlarged in the screwed portion, so that the sectional area of the spoke may not be diminished by cutting the thread. The rims are made out of lengths of steel of crescent-shaped section, which are first passed through a set of rollers to curve them to the desired circle; the meeting ends are then scarfed, pinned together, and brazed. Up to the present time the author is not aware that rims have been rolled weldless out of the solid, though there seems to be no reason why this should not be done. In Fig. 97, Plate 95, is shown a section of a solid rim and plain rubber tyre. Hollow rims are made in three ways:—1st, as shown in Fig. 98, by being rolled out of a length of solid-drawn steel tube; 2nd, as shown in Fig. 99, by being built up of two or more strips of steel plate, first rolled to the required section and then sweated or brazed together; 3rd, as shown in Fig. 100, by being rolled or drawn out of a single strip of steel plate, the edges of which form a lap joint and are then brazed together.

The rubber tyres are constructed of a round section, with either a plain or a corrugated surface; the latter gives a better hold on the surface of the road, and so prevents the wheel from slipping sideways. The tyres are also made of a combination of hard and soft rubber, the hard forming the wearing surface, and the soft the bedding surface or cushion. The tyre may be fixed to the rim by various methods, that usually adopted being to cement it in; if properly done, this is in every way satisfactory. Some manufacturers prefer to pass a wire along the centre of the tyre, and screw the two

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ends together by a right-and-left-handed nut. Various sections of rims have been tried for holding the tyre without any extraneous aid; two of them are illustrated in Figs. 101 and 102, Plate 95, but neither of these has been sufficiently long in use to afford evidence of their respective merits; if however after practical test they fail in their purpose, it would seem likely to be from want of cohesion between the tyre and the rim.

In a direct-spoke wheel a certain amount of windage must take place before the power is transmitted through the spokes to the rim. To obviate this, the spokes are sometimes fixed tangentially to the hub: in which case also they are generally made in pairs, each pair being threaded through a hole in the flange of the hub, and the outer or free ends being fixed to the rim by small lock-nuts or nipples. In order that the spokes may run tangentially, it is necessary to twist the wire just at the place where it is bent to form the double spoke; this double twist is rather a crucial test for the spokes during construction, and it is not surprising that they always give way first at that place. The latest method of constructing wheels with spokes tangential to the hub is to use single spokes threaded through transverse holes in the hub, and bent to run off at right-angles to the hole, so as to form a kind of hook, as shown in Fig. 90, Plate 92; the spoke ends are also headed, to prevent them from pulling through the holes, and are secured at the rim by nipples or lock-nuts.

One of the latest innovations in the construction of wheels consists in corrugating or crimping the spokes throughout their entire length, which gives a certain amount of elasticity to the wheel. At first sight it would seem as if these corrugations would seriously diminish the lateral stability of the wheel; but as far as experience shows, such is not the case. As however wheels so constructed have not been very long in use, it remains to be seen whether they will stand the wear and tear of the road.

Bearings.—The bearings of the wheels are now almost without exception made with anti-friction balls interposed between the moving parts. The most approved kind of ball bearing is that known

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as the "Æolus," illustrated in Figs. 103 to 105, Plate 96, which is adjustable concentrically, so that the bearing remains perfectly true after adjustment. On the axle A is fixed a collar C, with a shallow groove of circular section turned all round its circumference, into which are placed the balls B. These are enclosed within a concentric casing, which is formed in two parts, D and G. The part D is fixed to the frame of the machine, and the part G is a gland screwing concentrically into D; the inner surface of each part is coned, so that by simply screwing up the gland G the cones are tightened on the whole set of balls, and the bearing is adjusted concentrically. The gland G is prevented from working loose by a small toothed bracket J, engaging in notches round the edge of the gland.

In another construction of bearing, illustrated in Figs. 106 to 108, Plate 96, two facing cones GG are screwed from opposite sides into a cylindrical casing D, which is split transversely and provided with lugs on each side of the split, so that it may be tightened up by a screw to grip the cones within it. The bearings of the small wheels, as illustrated in Fig. 109, Plate 96, and of the pedals, Fig. 119, Plate 100, and also in many cases of the head, Fig. 111, Plate 97, are constructed in a similar manner. It has been ascertained from careful experiment by Mr. C. Vernon Boys that twelve balls in a bearing lost together only $\frac{1}{20 \cdot 8}$ grain in weight in running 1000 miles, or only $\frac{1}{250}$ grain per ball, which is equal to an actual surface wear of only $\frac{1}{158,000}$ inch.

Frame.—The frames of both bicycles and tricycles are largely constructed of weldless steel tube. The frame of a bicycle consists of two parts, the front fork and the backbone: both of which are made of weldless steel tube. For the front fork, the tube is drawn and tapered into an oval section, so as to give the greatest possible strength to resist the torsional strain produced when the rider pulls at the steering handles; the backbone is left of circular section, and is also tapered towards the back fork, to which it is brazed. The back fork is made out of a blank of sheet steel, bent and blocked into shape, the sides being of a half-round or crescent section. In some machines

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the back fork is constructed out of a prolongation of the backbone, which is first split up for some distance, and then blocked out into shape.

In the frames of tricycles the tubing is usually left of circular section, and varies in size from 1 to 1¼ inch diameter, and in thickness from 16 to 13 B.W.G. or 0·065 to 0·095 inch, according to the size of the machine and the weight it is intended to carry. Owing to the shape of the frames of tricycles, many solid parts are required; and these are chiefly made in wrought-iron or steel stampings. Although malleable-iron castings are extensively used for the purpose, their use cannot be too strongly condemned, as it has not unfrequently resulted in the total collapse of the machine while being ridden. The temptation to substitute malleable-iron castings for wrought-iron or steel stampings is great, on account of the crying demand for novelty in the construction of tricycles; and when it is considered that the existing patterns are constantly being superseded by new ones, which in their turn will be cast aside for further improvements, it will be seen that the cost of the new tools and stamps required, which must be charged to the cost of the tricycle, is very great; and the author believes that this is the real cause of the present high price of tricycles. When these have reached the same degree of perfection as bicycles, the prices of the standard patterns will doubtless adjust themselves to a lower level.

Steering Gear.—The steering gear may be dealt with under two heads:—1st, the method of mounting the steering wheel, so that it may be turned for the purpose of steering; 2nd, the method of controlling the wheel.

1st. The steering wheel of all bicycles and of most tricycles is carried in a vertical fork, at the top of which is a socket or head whereby it is connected to the other part of the frame, so that it may be turned for the purpose of steering. There are two varieties of heads, the "socket" and the "Stanley."

The socket head, which was the first used, is constructed as follows. From the top of the fork rises a pin tapering gradually upwards, and provided with a screw thread and nut at the top. Upon the pin is fitted a taper socket, attached to the other part of the

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frame, and adjusted and kept in place by the nut on the top of the pin. There are many objections to this make of head, and it is fast falling into disuse, being superseded by the "Stanley" head, so called from the name of the machine on which it was first used.

In the Stanley head, as illustrated in Fig. 110, Plate 97, the top of the fork is formed with a cylindrical socket H, in the back part of which is a slot. Within the socket is placed a short spindle S, attached to the frame of the machine by a narrow web called the neck N, which passes freely through the slot in the back of the socket. The ends of the spindle S are coned, and work in corresponding coned bearings; the bottom bearing which carries the load is in the bottom of the socket, and the top bearing is in an adjustable set-screw or cap screwed down into the top of the socket and secured by a lock-nut. The spindle S is made as long as possible, in order to give increased steadiness. Sometimes balls are introduced between the coned surfaces, as illustrated in Fig. 111, in order still further to diminish the friction. In Fig. 112 is shown a modification of the Stanley head, in which a pin P is passed down through the neck-spindle S, and is screwed into a steel cup C fixed in the bottom of the head H. After the head is adjusted, the pin P is locked by the split coned nut at top. This arrangement gives increased rigidity and wearing surface, and consequently the head is less liable to wear loose and shaky.

Some modifications have been introduced in the method of mounting the small steering wheels of tricycles, chiefly with the object of using a larger steering wheel and of increasing the rigidity of the frame. One such plan consists in mounting the wheel in quadrant bearings, as illustrated in Fig. 113, Plate 98. In another method, illustrated in Figs. 115, 116, and 117, Plate 99, the hub of the wheel is of skeleton make, its flanges F being connected by three or more bars B; and it is mounted on ball bearings upon a short hollow stud-axle A, with a suitable cap C at each end for adjusting the bearings. The hollow axle is itself pivoted vertically at the centre of its length upon an internal bar D, the ends of which are fixed in the frame of the tricycle. The wheel is steered by the horizontal arm E projecting from one end of the hollow axle, whereby

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this axle can be swivelled horizontally upon the bar D through the extent of the clearance between the bar and the bore of the hollow axle. Either of these two arrangements enables a large steering wheel to be used without adding to the weight of the frame.

2nd. Of the means of controlling the steering wheel in an ordinary bicycle little need be said, as it consists of a transverse handle-bar fixed on that part of the head which is attached to the fork carrying the steering wheel. Safety bicycles that are not controlled like ordinary bicycles may be classified under tricycles.

The ordinary method of steering a tricycle is by a rack and pinion. The pinion is fixed to a vertical handle, mounted in bearings so that it can revolve; and the rack forms part of a light rod, the free end of which is connected with an arm fixed on the fork of the steering wheel. This method of steering is illustrated in Figs. 35, 39, 67, &c. Another mode is by a transverse handle-bar, as used on a bicycle. In some machines the handle-bar is mounted on a spindle connected direct with the fork of the steering wheel, as illustrated in Fig. 114, Plate 98. In others the spindle carrying the transverse handle is connected with the fork of the steering wheel through levers and connecting-rods, as illustrated in Fig. 91, Plate 93. Both these methods of steering are used in safety bicycles having the steering wheel in front, as shown in Figs. 16 and 18, Plates 65 and 66.

Owing to the sensitiveness of this mode of steering, mechanism has been devised for controlling the steering wheel, and keeping it running in a straight line until it is moved by the rider for the purpose of steering. The most effectual is that applied to the machine illustrated in Fig. 114, Plate 98. It consists of a V shaped cam, fixed on the steering spindle, and lying in a recess of similar shape in the top of the socket through which the spindle runs, and kept therein by a spring. When the machine is steered to either side, the V shaped cam is forced out of the groove; and consequently its tendency is to re-seat itself, and so bring the steering wheel back to the straight line.

Brake.—Both for bicycles and for tricycles there are but two varieties of brake:—the spoon brake, and the band brake. The spoon

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brake, which is now almost the only one used on bicycles, consists of a spoon lever so pivoted that it may be brought to bear upon the circumference of the driving wheel, or of both the driving wheels if used on a tricycle. On a bicycle it is worked by a hand-lever pivoted to the handle-bar, so that it may be grasped by the rider without releasing his hold of the bar. By proper proportion of leverage a great power is obtained; so much so that, unless care is exercised in applying the brake, the driving wheel will be suddenly stopped and the rider will be thrown off.

The band brake, which is the one now used on nearly all tricycles, consists of a steel band lined with leather, and encircling a drum that is fixed on the driving axle. The ends of the band are connected to a hand-lever, by which the band is tightened round the drum so as to exert the necessary retarding force. In some of the central-geared tricycles the band brake is applied to the pedal crank-axle, and is put on by the foot, as illustrated in Fig. 118, Plate 99. This arrangement proves a valuable addition to any tricycle as an emergency brake.

Pedals.—The pedals of all bicycles and central-driving tricycles are similarly constructed, being mounted on pedal pins which are bolted to the cranks. On the cranked axles of side-driving tricycles the pedals are mounted direct on the cranks, and have therefore to be made in two halves so that they may be put on. In many cases the pedals are mounted on ball bearings, Fig. 119, Plate 100. Pedals are made in two varieties, known as rubber and rat-trap: the former have rubber surfaces, which absorb a great deal of the vibration; the latter have roughened steel plates set on edge, and give a better hold for the feet, but are not so comfortable in use as the rubber pedals, as they do not absorb the vibration. Some years ago the author designed the combined rubber and rat-trap pedal illustrated in Fig. 120, Plate 100, which is constructed with rubber bars on one side and rat-trap plates on the other, so that it gives the advantage of both varieties; this pedal is now largely used both for bicycles and tricycles.

One of the chief elements of danger in riding a bicycle consists in the foot slipping off the pedal when a great amount of power is

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being exerted in driving; and as this instantly throws the centre of gravity in front of the driving-wheel axle, the rider is thrown off in front. Various devices have been fitted to pedals for gripping the feet, so as to remove this source of danger. The first introduced was that illustrated in Fig. 121, Plate 100, in which the side plates of the pedal, or two auxiliary plates A A fixed to them, are curved upwards and slightly inwards, so that the foot jams itself between the plates and is held secure. But this is found to deprive the foot of the slight lateral movement required by the leg when exerting downward pressure; and often the foot gets so tightly jammed in the grips that it cannot be released quickly enough for enabling the rider to dismount suddenly when occasion requires. After an extended experience with these pedals the author designed the grip-pedal illustrated in Fig. 122. The grips on this pedal consist of a pair of small bell-crank levers, pivoted on the front plate of the pedal on either side, and close to the side plates. The vertical arms of the levers have flat jaws J J, which can be bent to the shape of the foot. When the foot is placed on the pedal, it bears on the horizontal arms H H of the bell-crank levers, and causes their vertical arms with the flat jaws to turn inwards and grip the foot: so that, as long as any pressure is exerted on the pedal, it is impossible for the foot to slip, but immediately the pressure is removed the foot is automatically released.

Fittings, &c.—Of the fittings and accessories of cycles, such as saddles, lamps, bells, distance-indicators, spanners, lubricators, &c., the varieties are far too extensive for enumeration; but many display an amount of ingenuity which will repay an inspection of them. The manufacture of these fittings forms separate trades, which employ a large amount of capital and labour.

In conclusion the author desires to acknowledge with thanks his obligations to those manufacturers and others who have so courteously rendered him every assistance for the preparation of this paper.

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Discussion.

Mr. Phillips took the opportunity, before the discussion commenced, to draw attention to the remark by which the paper was qualified at the outset (page 470), namely that wherever he had had occasion to mention any particular machine by name he had done so only in a typical sense, and not as expressing an opinion that the machine referred to was better than others.

For the loan of the numerous cycles and details which had been exhibited in illustration of the paper during its reading, he was indebted to the courtesy of the several makers.

Mr. C. Vernon Boys, referring to the completeness with which the author had treated his subject, considered that a paper of this kind, bringing up as it did to the present date everything that had been done, would in future years be exceedingly valuable.

In regard to dwarf bicycles with geared rotary action, the explanation offered in page 472 might be sufficient to account for their extraordinary efficiency; but he thought there were two other points of the utmost importance, which had hardly been adequately dealt with. One was the most important fact that a smaller machine encountered very much less resistance from the wind. He was not speaking so much of roadsters on ordinary roads; but when driving a racing bicycle on a racing path he believed the chief resistance which had to be overcome was that of the wind against the spokes; and in a small wheel this resistance must be much less than in a large one. Again, on a smaller machine the rider could adapt the saddle and treadles to one another in such a manner that he could be working in a comfortable position; he had not to strain himself to the utmost in order to ride a wheel as big as possible.

In reference to the Otto bicycle, which he had ridden a good deal, he disagreed with the statement in page 478, that "if a very sharp turn has to be made suddenly, a brake is applied to one wheel at the same time that its driving band is slackened, which causes the machine to turn round in a circle upon that wheel as the centre." That practice he considered was a bad one, and was liable to rub the

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tyre off the stationary wheel. The proper way of turning in a short space was to let one wheel travel on, and back-treadle the other wheel, so that the latter was going backwards at the same time that the former was going forwards, the pair turning on a vertical axis which passed through the rider's own body. This plan would not rub the tyres off, and it occupied only half the space in turning; but of course it could not be adopted in riding at any speed.

The subject of double-driving by clutch action and by differential gear had been treated very completely by the author; but greater preference he thought had been given to the clutch system than it deserved. His own impression was that the differential gear was by far the most perfect system of driving; but very great advantages were of course given by the clutch, and these had been well put forward in the paper. It was stated in page 480 that "as only one wheel drives when the machine deviates from its straight path, the clutches in order to drive satisfactorily must be instantaneous in their action, in order that both driving wheels may be locked to their respective chain-wheels or axle immediately on the machine again running in a straight line." When going round a corner—and this point had hardly been made quite clear—only one wheel was driven, and that was the wrong wheel, being the wheel on the inside of the curve. The result was that, if the rider wished to turn the machine, more especially to start from rest, round a very sharp corner, the whole driving power was exerted on the inner wheel which was hardly moving; consequently the strain then thrown on the tyre of the steering wheel was far greater than could be produced in ordinary riding. In the case of a differential-geared machine, any inequality arising from the mud or other road resistance certainly produced a differential action tending to make the steering wheel skid sideways: but the lateral strain in this case was nothing in comparison with that produced on the steering wheel in a clutch-driven machine when starting round a sharp corner. In the latter mode of driving, the result under these conditions was that the steering wheel skidded along, and that the rubber was apt to be thereby torn off. Reference had been made in page 481 to a possible kind of clutch, which he should like to see when completed, that

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(Mr. C. Vernon Boys.)
would be almost if not quite instantaneous in action, whether driven forwards or backwards. Some two years ago he had seen at Horsham, at the house of Mr. Burstow, the inventor of the Centre cycle—which machine had not been referred to in the paper—a contrivance that appeared to accomplish everything the author had alluded to. It was a species of clutch acting either way, so as to drive the wheels either forwards or backwards. Whether it had any defects he did not know, as he had not been shown how it was constructed: and he only mentioned it as showing that such a contrivance had been made.

The driving bands used on the Otto bicycle had been referred to on page 486 as plain bands. As a matter of fact they were now lined with some material, either india-rubber or canvas; but this was a detail of little importance. The objection urged in the paper against that system of driving was the fact that power was lost in perpetually bending the steel bands over their pulleys, and then letting them become straight again. Whether any power was thus lost or not, he was hardly prepared to say. In bending a ribbon he imagined that, if it was not bent past its limit of elasticity, its tendency to become straight again would then cause the total work done in bending to be practically nothing. There was however an objection which had not been referred to, namely that the bands being tight kept the bearings under a strain, so that when doing no work the bearings did not run so freely as they would when chains were used for driving. When doing heavy work the driving bands were preferable to the chains, because the diameter of the band-pulleys was so much larger than that of the chain-wheels, and the actual pull of the bands was therefore proportionately less.

The Oarsman tricycle (page 491) he had seen a few months ago near Beaconsfield, where Mr. Taylor the inventor lived, and he had ridden it then a mile or two along the road. The driving power, though apparently communicated by the hands as in rowing, was in reality almost entirely communicated by the muscles of the body. The back of the rider pressed against a cushion, and that cushion pulled the driving cords, so that almost the whole power was exerted, not through the rider's arms at all, but by his legs. He sat on a

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sliding seat, like that on which a rower sat in a boat, and the work was done by the muscles of the legs and body; all that the arms had to do was to complete the stroke at its finish. There was one point in the Oarsman which was not at once obvious, namely that, though it was a clutch-driven machine, it had all the advantages of a differential-geared machine. The reason was that the horizontal handle-bar, which was supported by the driving cords, was not compelled to remain in a rigidly transverse position; but when one cord which drove the wheel on that side had to move faster than the other, owing to that wheel having to run faster round a curve, the handle-bar could swivel askew to any extent of obliquity, so that the hand on the side of the quicker wheel could make a longer stroke than the other. There was a certain degree of similarity therefore, so far as the driving was concerned, between such an action and that of sculling round a curve when a greater stroke was taken with one arm than with the other. Of course the handle-bar resumed its true transverse position again during the return stroke. The chief objection to the machine was its great weight, and its very great sensitiveness in steering, in consequence of which he had been afraid to make it go quickly; that however was of course a matter of practice, and there were other machines which a rider found very sensitive at first. These objections were largely due to the fact that the machine was the work of Mr. Taylor's hands; and though the construction was strong, the workmanship good, and the result more than creditable, it was not to be supposed that a country clergyman could turn out a machine comparable in lightness and finish with the beautiful examples of Coventry work which were here exhibited in illustration of the paper.

With regard to the permanence of the corrugated spokes mentioned in page 499, he had himself ridden with corrugated spokes ever since last Christmas down to the present time, over a distance of 3800 miles, on roads of every kind; and they showed no sign whatever of becoming less elastic or giving way. At first he had ridden on them with the utmost fear, suspecting every moment that the wheels would give way; but he now believed that the wheels with corrugated spokes were really less liable to suffer from sudden blows than the

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(Mr. C. Vernon Boys.)
ordinary wheels with rigid spokes. Against a continually applied force he did not think they would be stronger, but only against a sudden blow. They had met with rather a severe experience a few months ago, when going very quickly along a rough road; the axle broke, and one wheel went over on one side, and the other on the other side, carrying the machine with it; but neither wheel was in the least damaged.

On the wear of the balls in ball bearings he had made some experiments, which were perhaps of no interest to cyclists generally, but were worth the notice of mechanical engineers. When the balls were taken out after every two hundred miles and examined and weighed, he had found that their wear was, as stated in page 500 of the paper, at the rate of 1–250th of a grain per ball for every thousand miles. On afterwards running the machine a thousand miles without taking the balls out at all, he found to his surprise that the wear was almost identically the same as in any one of the previous runs of only two hundred miles. He therefore concluded that the amount of wear was due, not to the actual proper rubbing and rolling of the balls round the bearing, but to such little dirt as could not be prevented from getting in whenever the cap was taken off and screwed on again. The extraordinary result however came out, that, while in a thousand miles each ball turned about 1,400,000 times on its own centre, its loss of weight in turning that number of times amounted to less than 1–1000th of a grain: which might be taken as another way of saying that the balls did not wear at all. When the design of ball bearings was spoken of as bad, because the surfaces of the balls where they touched one another were going opposite ways, and instead of rolling were tearing themselves to pieces, he thought in view of the facts he had mentioned it was decried very rashly.

Mr. W. Silver Hall asked whether the corrugated spokes were corrugated longitudinally like the ribs of an umbrella, or transversely like a lady's crimped hair-pin.

Mr. Phillips replied that they were corrugated like a crimped hair-pin, as shown in Fig. 73, Plate 84.

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Professor Robert H. Smith observed that one merit peculiar to the Otto bicycle was that the full weight of the rider was borne upon the driving wheels. This was the only bicycle he believed in which the whole weight of the machine itself, as well as the full weight of the rider, was upon the driving wheels.

Mr. J. Lyons Sampson had seen an ingenious arrangement in which the wheels of a bicycle of the Otto type were driven through unyielding connections, whether going straight or round a curve, instead of depending on the uncertain friction of the bands used in the original make. The motion was communicated from the pedal crank-axle by a pitch-chain to a chain-wheel on the centre of the main axle. The two driving wheels were mounted on hollow axles, which ran loose on the main axle; each hollow axle was prolonged inwards to reach the chain-wheel, and had a worm-wheel fixed on its inner end. On each side of the chain-wheel a pair of brackets were fixed, to carry a small worm, which geared in the worm-wheel on the end of the hollow axle, and so compelled the two hollow axles and driving wheels to rotate with the chain-wheel when it revolved, as though they were all fast together on the main axle. As long as the bicycle was running in a straight line, the worms did not revolve in their own bearings, but were carried round the axle by the chain-wheel, and acted simply as couplings to lock the two worm-wheels to the chain-wheel. When it was desired to go round a curve, the worm on the inner side was made to revolve on its own axis, and so to over-run or retard its own worm-wheel in relation to the chain-wheel and the other worm-wheel, thereby causing the bicycle to describe a circular arc in virtue of the different velocities of the two driving wheels. For enabling the rider to rotate either worm, each was connected by a pair of bevel wheels and a pinion to a toothed wheel that ran loose on the hollow axle and formed part of a brake-wheel. The arrangement was such that, if the brake-wheel were checked while the chain-wheel was revolving, it caused the worm with which it was connected to rotate on its own axis and so make the bicycle turn towards that side; while on releasing the brake, the worm would cease to rotate, and the bicycle would resume

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(Mr. J. Lyons Sampson.)
a straight course. In practice it was found sufficient in running round a curve to give the inner wheel a speed of two-thirds to three-quarters the speed of the outer. A further advantage of this arrangement was that additional power for hill-climbing was obtained by simply checking the two brake-wheels equally, so as to make both the worms revolve together; the reduced speed thereby obtained gave a corresponding increase of power. A bicycle of this new construction was shown in the Inventions Exhibition; and he thought it was worthy of attention.

Mr. J. P. Dalby thought justice had hardly been done to one part which he believed to be of vital importance in modern tricycles, namely the balance-gear. When the late Mr. Starley invented the balance-gear, he believed he did more than he himself had any conception of at the time; and the tricycle of today would not be what it was, either in excellence of running or in extent of use, but for that balance-gear. In page 483 of the paper a sort of test was suggested for trying the action of the two kinds of gear, by disconnecting the steering wheel so that it might trail and run free, and placing an obstruction in the path of one of the driving wheels; and it was represented that a clutch-driven machine, *if its impetus were sufficient*, would pass over the obstacle without deviating from the straight line, while a differential-geared machine would swerve round to the side on which the obstacle occurred, and would *probably* fail to pass over it. The question he thought was not one of the mode of driving, but of impetus; and he believed that any machine, however it was driven, would pass over the obstacle if its impetus were sufficient, and that the probability of its failing to do so was not much greater with the one mode of driving than with the other. From the result of the test as represented in the paper, it was there inferred that in differential-geared machines it was therefore important to have sufficient weight on the steering wheel for ensuring its controlling the action of the differential gear. But from his own experience as a rider he considered this inference to be erroneous, because in a differential-geared machine it was well known that the weight on the steering wheel could be reduced to a minimum; whilst

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if it were not for the differential gear, a good deal more weight would be required on the steering wheel than at present.

Another matter of some importance in connection with differential-geared machines was their steady running. The clutch-driven machine was not so certain in its steering as the balance-geared machine. In the latter, whatever power one wheel got the other wheel got also. In going round a curve, the outer wheel, because it was describing a greater curve and was consequently acting at a longer leverage, was therefore also doing more of the driving of the machine; and thus the balance gear conduced to taking the curve more readily than would otherwise be the case.

Mr. F. Warner Jones thought there was room for something more to be said respecting the principles of the construction of cycles; and he trusted the correct dimensions to be followed in the building of cycles would shortly be laid down, as had already been done so successfully in regard to yacht building. Being a new study, self-propulsion had scarcely received any large amount of attention from scientific men. In regard for instance to the high speed of the safety bicycles, which when first brought out were imagined to be a great mistake, it might be interesting to consider how so high a speed had been got out of them; and he should be glad to explain how this was. No doubt a great deal was due, as had been properly stated by Mr. Boys, to the diminished resistance they encountered from the wind. In the ordinary type of bicycle, one wheel was behind the other, the rider's weight being carried as much as possible over one large wheel; and, as rightly stated in the paper, the proper position for the seat in any cycle, for enabling a rider to exert the greatest force, was about 7 inches behind the crank-axle; and since on the level this proper position might be taken safely, the ordinary bicycle was the faster machine on the level. But there was this disadvantage in the ordinary bicycle with respect to the matter of safety, that in going down hill the rider on a higher wheel was thrown much further forwards than when riding on a lower wheel—in relation not to the centre of the wheel, but to the point of contact with the ground, because this point of contact was

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(Mr. F. Warner Jones.)

itself at the same time further behind in a larger wheel than in a smaller one. Therefore the larger the wheel, the further ought the rider to sit behind it for road riding. In the safety bicycles the smaller driving wheel allowed the rider to sit further forwards than he could on the ordinary bicycle; and he could therefore sit at the proper distance of only 7 inches behind the crank-axle, instead of being compelled for safety to sit further back than 7 inches as he was obliged to do on a larger wheel of which the centre was the crank-axle. Moreover the bigger the wheel and the higher the rider, the greater was the leverage at which the wind resistance acted upon him and the more important did this resistance become. In a safety bicycle with geared rotary action there was a great deal of friction in the necessary multiplying gear, which might perhaps balance the greater resistance of the wind against the ordinary bicycle with a larger wheel driven direct. The speed of the safety bicycle was therefore undoubtedly due to the better position in which the rider could sit in respect to the crank pedals. With the hinged fork-ends, shown in Figs. 11 and 12, Plate 64, the rider's seat ought of course to be shifted horizontally for each adjustment of the crank-axle, in order that the seat might be kept at the correct distance of about 7 inches behind the crank-axle for enabling the rider's power to be exerted always at the greatest advantage.

Bicycles having the driving wheel in the rear, as in Fig. 16, Plate 65, possessed the advantage of greater safety; but they did not generally go quite so fast perhaps as those having the driving wheel in the front. One reason of this he believed to be the greater length of wheel-base, and the fact of the rider not being seated so nearly over the centre of the driving wheel. In Fig. 17, Plate 66, the rider however was enabled with a minimum wheel-base to sit almost over the centre of the driving wheel, which was the proper position when the steering wheel was in front, the rider's distance in front of the driving axle being the measure of the weight or power necessary to be expended in the propulsion. Having a divided pedal-axle and a swinging frame, this bicycle consequently combined the advantage of the ordinary safety bicycles in which the rider's weight was carried almost over the axle of one wheel, with that of the Otto bicycle in

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which the necessary weight only was suspended in front of the driving axle.

In regard to the Otto bicycle, it had often been remarked that one of these machines with a pair of 56-inch wheels could be driven up a hill more easily than one with only 48-inch or 50-inch wheels, although the theoretical notion would be that the smaller wheels ought to go easier. The fact was that the swinging frames of bicycles and tricycles were not perfect for all sizes of wheels or heights of riders alike; and it had now been found, as a matter simply of practical experience in riding, that on the steepest gradients the swing frame was more advantageous to some riders when the driving wheels were 56 inches diameter than when they were smaller. The explanation was that the principle of the swing was not affected by the position of the driving axle alone; for if on a steep ascent the rider's whole weight were behind the point of contact of the wheel with the ground, his swinging forwards would not enable him to exercise the slightest power for progression. Hence the dimensions of the swing must be so conformed to the size of the wheels and the height of the rider that in going up hill his centre of gravity should be swung far enough in front, not of the driving axle, but of the point of contact with the ground, to enable the amount of his weight in front of this point not merely to balance the amount behind it, but also to leave a sufficient excess in front for power, and at the same time to place him in the proper position for exerting his power on the crank-pedals to the greatest advantage. The rider's length of leg and of back should therefore regulate the size of the wheels, in order to obtain the best results in swing cycles.

In all cycles driven by endless chains working in an inclined position from the crank-axle to the driving axle, it would be observed that the lower span of the chain hung from the chain-wheels at points which were rather further apart than those from which the upper span hung. The lower span being therefore slightly heavier kept the upper span always taut; and consequently, when the upper span was the driving one, as in the case of bicycles driving the rear wheel, there was no back-lash; but when the lower

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(Mr. F. Warner Jones.)

was the driving span, as in safety bicycles driving the front wheel, there was always a slight back-lash. In the latter therefore the more perpendicular was the chain, the less would be the back-lash.

With reference to corrugated spokes he concurred with what Mr. Boys had said. When he first saw them himself, he thought they must be weak; but he had found the principle of construction was entirely correct, and he was satisfied the wheels with corrugated spokes were some of the best wheels made. There was an india-rubber tyre on the wheel; and with the corrugated spokes it was as though the wheel were made of india-rubber all over. If a blow was received in any direction, the spokes would slightly give and rebound.

With regard to the tangential spokes mentioned on page 499, there was a difference of opinion as to their value. If only a pair of spokes at right angles to the pedal-cranks were put in tangentially to the hub, and the rest of the spokes were all kept radial, that mode of construction he thought would be quite as effective as if all the spokes were made tangential.

Mr. Boys mentioned that a rise of 1 in 10 was considered a steep hill; and on such a rise, with wheels of 54 inches diameter or 27 inches radius, the point of contact of the wheels with the ground was only 2·7 inches in front of the axle, an amount through which the body could be easily moved. As a matter of fact on his Otto bicycle he had ridden up Muswell Hill, which at the top had a gradient of 1 in 7·8; the machine weighed over 100 lbs., and the driving wheels were 57 inches diameter; and he had not experienced any difficulty in keeping the necessary position by means of the swinging frame; in fact it was only by acquiring such a position that he could have got up at all.

Some time ago it was true he had himself made the remark that he could go better on an Otto bicycle with big wheels of 56 inches diameter than on any other sizes; but since the elastic spokes had been introduced he had now found that the best size had been brought down to 52 inches. Another rider, with whom on 56-inch wheels he had previously been pretty equal, could now with 52-inch

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wheels outrun him, whether going up or down hill. The reason he was not able to explain; but perhaps it was owing to the increased lightness and ease of management of the smaller wheels.

Mr. Phillips in reply said that, in reference to the dwarf bicycles with smaller wheels, their greater efficiency as compared with ordinary bicycles had been attributed by Mr. Boys to two causes: firstly the reduced wind resistance; and secondly the fact that the dwarf machine could be made to fit the rider more perfectly. While admitting that there was some advantage in the reduced wind resistance, he could not agree in the observation with regard to fit, as he considered an ordinary bicycle could be made to fit the rider as perfectly as a dwarf machine. From his own experience as a rider he did not think that either of the above reasons was as good as the one assigned in page 472 of the paper, namely that in the dwarf bicycle the driving wheel could be geared up to any extent to suit the rider, and that he could thus obtain a high speed with a slow pedal action which did not produce rapid exhaustion. No doubt by rapid pedalling a trained rider on an ordinary bicycle would travel faster along a road; but for a rider not used to rapid pedalling the slower pedalling in the geared bicycle would be a very valuable feature.

With respect to the rapid turning of the Otto bicycle, he was not a practical rider of that machine, and was therefore prepared to accept the statement of Mr. Boys, as to the mode of turning suddenly; but the mode described in the paper was to a certain extent correct he considered, inasmuch as Mr. Boys had himself admitted that the method which he preferred to adopt could not be used when travelling at a high speed.

The driving gear alluded to by Mr. Sampson he presumed was that of Mr. C. K. Welch. He had himself seen it, but was unable to say anything about its practical working, because it had not yet been tried; indeed the only specimen at present made was the one shown in the Inventions Exhibition. From what he had seen of that specimen, it appeared to have the defect that the machine could not be turned in a sharper curve than one of about 4 feet radius;

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(Mr. Phillips.)
but this could no doubt be altered by a different proportion and arrangement of the gear.

With regard to the two methods of double-driving, in the comparison made in the paper he had by no means intended to praise the clutch action as against the balance gear; on the contrary he quite admitted that he had never seen a clutch-driven cycle which was perfect, and furthermore that at present there was not any plan of double-driving which approached the balance gear. What he had said of the clutch action, and what he still maintained, was that, if it could be made to drive perfectly backwards as well as forwards, it would make a better driving gear than the balance gear; but this had not yet been accomplished.

With respect to the test suggested in page 483 of the paper, regarding the relative actions of the clutch and the balance-gear, the reason why the driving wheel of a clutch-driven machine would surmount an obstacle in its path, while that of a balance-geared machine would fail to do so and would cause the machine to deviate from the straight line, was that in the clutch-driven machine neither wheel could lose motion relatively to the other, and consequently both wheels must receive an equal amount of the driving power at all times when running in a straight line. In the balance-geared machine on the other hand either wheel could lose motion relatively to the other; and therefore, if one wheel met with a greater resistance than the other, it did not receive an equal share of the power expended, as the power was differentiated between the two driving wheels in inverse ratio to the resistance encountered by each. He could not agree with Mr. Dalby that the weight on the steering wheel of a balance-geared tricycle could be reduced to a minimum; this theory was refuted by present practice; and the unsteady action of many front-steering tandem tricycles fitted with balance-gear, when running at a high speed, he considered was entirely due to this cause.

The Centre cycle he had seen, but it did not appear to him to be a sufficiently practical machine to merit notice. The clutch however, referred to by Mr. Boys, he had not yet seen.

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It had been noticed by Mr. Boys that the driving bands used on the Otto bicycle were lined with india-rubber or canvas; in the paper they were called plain in contradistinction to the perforated bands. The thickness of the unperforated steel bands on the Otto machine was only about 1-100th of an inch; but the perforated bands were four or five times thicker, and it was the flexure of these thicker bands over their pulleys which took such a considerable amount of power. He did not agree in considering that driving bands were preferable to chains for doing heavy work, inasmuch as the diameter of the chain-wheels was not in any way limited, and they might be used as large as the band-driving pulleys. With equal-sized chain-wheels and pulleys he thought the advantage would lie with the chain method of driving.

With regard to the Oarsman tricycle, which he was sorry not to have been enabled to illustrate or exhibit to the meeting, the inventor, Mr. Taylor, had recently been making further improvements in it; and he hoped to be able both to illustrate it and more fully to describe it, in order that fuller justice might be done to it in the paper.*

In reference to the corrugated spokes, he was very glad to hear the observations of riders who had tried them and who believed they would prove successful. His only fear had been that, if there was much elasticity in the spokes, the wheel would not be sufficiently rigid.

Mr. Charles Cochrane said that, in reference to the resistance of the wind against the wheels of any cycle, it appeared to him that the difference in this respect between large and small wheels could hardly be material in comparison with other more important factors of resistance to the motion of cycles.

Mr. Phillips believed both of the speakers who had raised that point referred to the resistance in passing through the air, and not

* The description and illustration given in the paper were obtained subsequently to the Meeting.

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(Mr. Phillips.)
to the resistance of the wind which might be blowing, and which might be either in favour of the rider or not. But they were of opinion that the smaller wheels encountered the least resistance from the air; and he was himself prepared to endorse that opinion.

Mr. H. J. Lawson asked whether it was considered that when there was any elasticity at all in a wheel its true circular form was then to some slight extent destroyed under the load; and if so, how that could be an advantage. It seemed to him that any elasticity in the wheel itself must either destroy the circle, or else impair the driving power in the centre of the wheel. Either objection appeared to him to be a fatal one, even if the elasticity were the slightest possible.

Mr. Phillips considered it might be taken for granted that the corrugated spokes had not such an amount of elasticity as would alter the position of the axle with respect to the circumference. If they had, the stability of the wheel would be destroyed at once.

Mr. Boys thought the elastic yielding was so minute that the change of form in the wheel would not be perceptible to the eye.

The President was sure the meeting would agree with him that the paper had been written in a fair and considerate spirit; in fact the impression he had himself received from it was that the greatest care had been taken by the author to avoid wounding the susceptibilities of any one.

It had been remarked by one speaker that the principles on which cycling depended had not yet been sufficiently examined; and with that remark he agreed to a certain extent. Far more questions he thought remained to be discussed than had arisen at the present meeting. For example, there was the question whether the path of a bicycle was really wavy or straight. He had often watched an expert bicyclist proceeding along the road, and had not been able to detect any regular deviations from side to side; and on following the track afterwards he could scarcely find any departure from a straight line. That raised the point whether the rider really did put

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his weight first on one side and then on the other, involving correction by under-running; or whether, when he pressed his foot on one side upon the crank, he did not at the same time incline his body towards the other side, so as to keep the centre of gravity always in the same vertical line. This was a point upon which he had not himself made up his mind; and he should like to hear it further discussed on some future occasion.

He had heard it gravely asserted by persons who had never ridden on cycles that no real advantage was obtainable from them; but that the natural method of progressing on our own legs must of necessity be the most perfect under all circumstances. That assertion might be answered by pointing to the fact that our legs were adapted to many and very varying circumstances, such as going upstairs and downstairs, jumping, walking, running, dancing, and the like. But just as a knife that was made to answer all sorts of different purposes was not the best possible for any one particular purpose, so it was with our legs. The advantages to be derived from cycling were realised under the special conditions in which alone it was admissible at all, namely on a good hard road. The advantages were that the rider's weight was borne altogether on the wheels, and that his strength became available wholly for propulsion. The muscular effort exerted in carrying the weight of the body, when progressing on the legs, was greater and more fatiguing than that exerted in merely urging it forward. A horse drawing a carriage would convey half a dozen persons in it with tolerable ease on a smooth road; but if those half dozen persons were carried on his back it was quite clear that he would soon be exhausted, notwithstanding that he had not then the additional weight of the carriage to contend with.

It had also been pointed out that there was a great advantage in a low speed of pedalling. Men appeared to be so constructed that they were soon exhausted when they had to move their limbs with great speed. Whether or not this was in consequence of having to overcome the inertia of their limbs at each reversal of the motion, he hardly knew; but it was clear that a man could exert his strength far better by a greater effort at a lower speed than by a smaller effort

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(The President.)

at a higher speed; and in cycling he was enabled to do the former by the contrivances which were arranged for allowing of a low speed of pedalling.

Cycles were in his opinion wonderful pieces of mechanism. Of late, people had become so accustomed to them that they had ceased to admire them, and indeed often regarded them as nuisances. But when it was remembered that they had been rendered practicable only by means of a combination of subsidiary inventions, the development of which had occupied many ingenious minds over several years, it was not possible to help being impressed with their value. Without india-rubber, for example, and without the perfection to which this material had now been brought, modern cycles would be scarcely possible. One of their great features was that the india-rubber tyre partly acted as a spring, taking off the jar, and partly enabled the wheel to grip the road as the rider went along. If twenty years ago anyone had been told that the tyre of a wheel running along an ordinary road could be covered with india-rubber and would wear well, the assertion would not have been believed; it would have been said that the stones, grit, and other obstacles, would cut the rubber in pieces in a very short time. Then again, unless steel had been brought to its present state of perfection—in wire, in tubing, in stampings, forgings, castings, and so forth—cycles would not have been possible. The double-driving arrangement in tricycles he regarded as a most ingenious application of mechanical principles. The rider could go in a straight line or in a curve, and could turn in any direction and even make a complete circle, with the same force on each driving wheel. Without that invention tricycles would have been most imperfect.

It was well known that cycles, like railway locomotives, depended largely on good roads. They were of very little use if roads were in bad condition. It was proposed to lay down what were called cycle-ways by the side of ordinary roads in populous localities. With the great number of cycles now in use, and the number of people deriving pleasure and utility from them, the time he believed would come when those ways might be laid down with great advantage.

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Anyone who had had experience in the recreation of cycling must have found what an exhilarating thing it was to feel that one could go along at eight or ten miles an hour on country roads solely by one's own strength, on a machine which did not cost much, and which, unlike horses, consumed nothing while idle. Cycles gave their riders a sense of power over nature, previously unknown. Many persons had supposed that cycling was only to be taken advantage of by young men or boys, in the prime of life and bodily strength. That however was not the case. There were many middle-aged and even aged men, of corpulent habit, who if they would only try cycling would derive the greatest possible satisfaction from it. In fact a heavy middle-aged man would find that the machine carried his weight and enabled him to devote all his strength to propulsion. Then there was the case of cripples. Only very recently he had seen a working man who had one wooden leg—so that he could not have got on by himself at the rate of more than a mile and a half an hour—going along on a specially arranged tricycle at the rate of about seven miles an hour with ease, and carrying his traps with him. That man could not have lived in the country, and gone to and fro to his work, but for such assistance. Cycling must prove a great advantage, he considered, to numbers of working men who had to go to and from their work, as it would enable them to live out in the fresh air of the country, instead of being crowded up in smoky towns.

The invalid chair which had been exhibited was also he thought well worthy of notice. There were many cases in which invalids would be greatly benefited by going into the country or to the seaside; yet they could not bear the noise, the shaking, and the worry of railway trains. If they attempted the journey in the ordinary way, they had usually to face the difficulty of repeated mountings, dismountings, changes, and detentions. These were trifles to the healthy, but often serious obstacles to the sick. By means of the invalid chair such persons could be taken with minimum fatigue perhaps fifty or sixty miles to the seaside, to the very door of the house to which they were going. Such a mode of conveyance might often effect the saving of life.

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(The President.)

Before leaving Coventry he was sure the members would wish to express their appreciation of the excellent work they had seen in the examples which had been displayed before them, and of the ingenuity evidenced in the various details of the cycles shown. It was quite impossible that such work could be produced without skilful workmen, special machinery, and an elaborate system. Each of the different types appeared to him to have its own points of advantage; and generally speaking all were so good that any one wishing to get the best possible cycle would be utterly bewildered in deciding which to choose.

He proposed a hearty vote of thanks to Mr. Phillips for the excellent paper which he had read.

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MEMOIRS.

Peter Duckworth Bennett was born at Hawarden, near Chester, on 5th May 1825, and died on 28th November 1885, at the age of sixty, from an accident met with on that day. From 1839 to 1846 he was articled at the Oak Farm Iron Works, near Dudley, where he went through the fitting shops and the drawing office, and on the termination of his articles took the management of the constructive department. From 1847 to 1852 he was in the service of Messrs. Cochrane and Co., Woodside Iron Works, near Dudley, where in 1850 he took the position of chief of the drawing, estimating, and constructing offices. In 1852 he became chief engineer at the works of Messrs. Fox Henderson and Co., Smethwick. In 1853 he commenced business on his own account as a mechanical engineer at Spon Lane Foundry, Westbromwich, being principally engaged with work for railways and gas works. In 1878 this business was amalgamated with that of the Horseley Iron Works, Tipton, of which from that date he acted as managing director and engineer. He was a Member of this Institution from 1854, and a Member of Council in 1885. As chairman of the Sandwell Colliery he was instrumental in starting the trial sinking in 1870, and in prosecuting it perseveringly to the success realised in 1874 by the proving of the Thick coal at a depth of 418 yards (see Proceedings 1876, page 330). He was a justice of the peace for the county of Stafford, a member of the South Staffordshire Mines Drainage commission, and formerly for many years chairman of the Westbromwich commissioners.

Thomas Horsley was born in Derby on 25th May 1825, and died at King's Newton, near Derby, on 21st November 1885, at the age of sixty. After being educated at Derby, he was articled in 1840 as pupil to Mr. Josiah Kearsley, locomotive engineer of the

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Midland Railway at Derby; and was on the first engine that ran from Derby to Nottingham. When out of his articles, he assisted for a short time his father, who was engineer and manager of the Alfreton Iron Works, Derbyshire. About 1845 he was appointed engineer and manager of the Milton Iron Works, Yorkshire, where at that time, besides good iron for the Sheffield steel makers, large engines were also manufactured; he there designed and made many large pumping engines for lead and coal mines, drainage engines for fens, rolling engines and various other engines. The hydraulic presses were made there for lifting the Conway tubular bridge, which were afterwards used also for lifting one end of the Menai tubular bridge. In 1854 he was appointed to erect the Norton Iron Works, near Stockton-on-Tees; and on their completion the first large bell for the Westminster clock, called Big Ben, and one of the quarter bells were cast there. About 1863 he was appointed engineer and manager of the Alfreton Iron Works, where he remained until he retired altogether from professional work in 1868. He became a Member of the Institution in 1868.

Walter Macfarlane was born in 1817 at Torrance of Campsie, near Glasgow. His parents were not in a position to give him anything but the most humble education; and at the age when most boys begin school he was placed with Mr. William Russell, jeweller, Glasgow, with whom he remained some years, studying after work hours at the night grammar school and the evening school of design. His inclination being to the forge, he became apprentice for seven years to Mr. James Buchanan, blacksmith, Glasgow. On the expiration of his apprenticeship, during which he had acquired remarkable proficiency at the hammer, he attached himself to the firm of Messrs. Moses McCulloch and Co., Cumberland Foundry, Glasgow, where in the course of ten years' service he rose to the highest position under the principals. He then commenced business for himself, and established a branch of ironfounding unique in every department. His first efforts were directed to supply the plumbing trade with castings so carefully got up that their several parts should fit together with the utmost nicety. Successful in this,

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he applied cast iron to sanitary purposes, for which in his opinion it was peculiarly suited by its impervious nature; in this branch he introduced numerous sanitary improvements, the general acceptability of which has long been proved by their extensive adoption. Following on these he devoted much study to architectural ironwork, such as building fronts, verandahs, railway stations, conservatories, &c.; and in this branch he spent much time during the latter years of his life in bringing out the sixth edition of an elaborate catalogue of designs. The Saracen Foundry, Glasgow, of which he was the head, extends over eleven acres in Possilpark, and is the centre of a large population which has sprung up around since its establishment. His death took place on 18th October 1885, at the age of sixty-eight, after a few months' illness. He became a Member of the Institution in 1864.

George Wilson was born at Largo, Fifeshire, on 11th March 1829, being the second son of Mr. George Wilson, flax-spinner, who was afterwards at Haughmill and Prinlaws in partnership with the late Mr. John Fergus, M.P. for Fifeshire. After attending school at Kennoway under the late Mr. Bethune, he was sent by his father in 1839 in company with his two brothers, Henry and John, to the Collegiate School, Sheffield, his father having friends among the trustees of the school. As there was then no railway to Sheffield, the three boys went by the primitive wooden steamer "Pegasus" from Leith to Hull; thence by a small steam-boat to the village of Thorne on the river Don, and thence by coach to Sheffield. He was afterwards sent to the Madras College, St. Andrews; and finally to the University of Edinburgh, where he had the advantage of studying chemistry under Professor Gregory, the intimate friend of Liebig. In his seventeenth year he joined Messrs. Cammell and Johnson, the founders of the Cyclops Works, Sheffield, to learn the business of steel-making, his father being greatly impressed with the belief that steel would be one of the most important industries in the future. After a time he was sent by the firm to America; and he subsequently rose gradually to the position of manager of their business. On the death of Mr. Johnson, he became a partner of

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Mr. Cammell; and ultimately, on the formation of the present company of Messrs. Charles Cammell and Co., he was elected managing director; and on the death of Mr. Cammell he was appointed chairman of the company. His whole life was devoted to the prosperity of the business at the Cyclops Works, and thereby to the advancement of the interests of the town of Sheffield. In 1875 he had the honour as Master Cutler of entertaining the Prince and Princess of Wales at luncheon on the occasion of their first visit to Sheffield. As a man of business he acquired a high reputation, both in this country and on the continent, possessing very remarkable administrative combined with sound practical ability. His death took place from a seizure of congestive apoplexy whilst in the act of performing his duties at the works in Sheffield, on 1st December 1885, at the age of fifty-six. He was elected a Member of this Institution in 1859.

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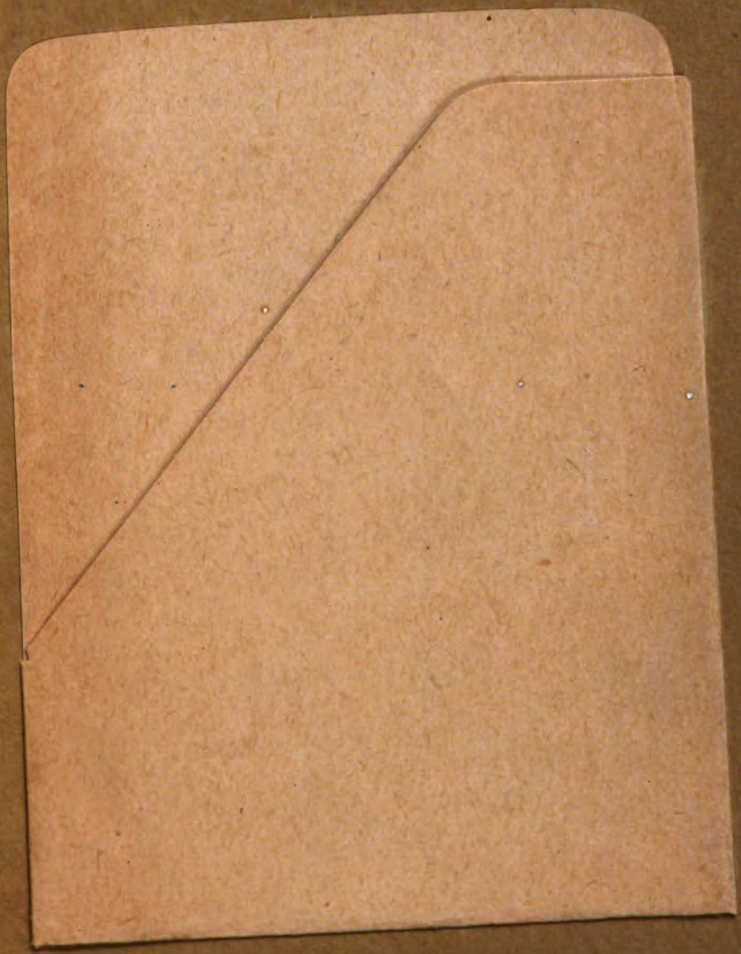

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